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A COMPLETE CLASS-BOOK

OF

NAVAL ARCHITECTURE

PRACTICAL, LAYING OFF, THEORETICAL

ames
BY

W. J. LOVETT
m

LECTURER ON NAVAL ARCHITECTURE AT
THE BELFAST MUNICIPAL TECHNICAL INSTITUTE

WITH NUMEROUS ILLUSTRATIONS
AND ALMOST 200 FULLY WORKED-OUT ANSWERS TO
RECENT BOARD OF EDUCATION EXAMINATION QUESTIONS

SECOND IMPRESSION

LONGMANS, GREEN AND CO.
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"Let us wait till the hour sounds. Till then, each man to his work. The hour will sound at last, but let us not waste all our time in seeking it on the dial of life."—MAETERLINCK.

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PREFACE

While the science of Shipbuilding is perhaps the most vital science of our country, its literature is of the scantiest. This want is nowhere more keenly felt than with the vast body of students attending technical classes, who have absolutely no book on Naval Architecture that will carry them through their courses of study. It is true there are such excellent Manuals as White's, Reed's, Campbell Holms's, Walton's, etc., but their application to technical students is limited, and their price prohibitive to most. In the shipbuilding world there are also a great many shipwrights, platers, draughtsmen, and others who would gladly welcome a book published at a reasonable price, which will supply them with a sufficiency of Naval Architecture for their ordinary and everyday needs, and enable them afterwards to study those higher works on the subject with intelligence and profit. The book will be found to be peculiarly adapted to the needs of students working for the Examinations of the Board of Education, as the syllabus of the course has been used as the basis for the work. A great many fully worked-out answers to questions set by the Department in the Elementary, Advanced, and Honours stages have been made an important feature, and it is hoped they will be of use to students. All abstruse matters not bearing directly on the subject have been rigorously excluded, and all technical statements and terms have been put in as plain and simple a language as possible. The door to one of the most engrossing and interesting of sciences has been too long shut to the actual workers and creators of the results of that science, and it is hoped that, with this book, the shipbuilder, be he only a rivet-boy, will be enabled to enter and see the vast possibilities of the intelligent study of the problems which have to be considered in the building of a ship. It is the earnest wish of the author that this book shall be a real help, and he will be pleased to receive and carefully consider any suggestions from teachers and students that may render it more useful, and he would more particularly ask for fully answered recent Science and Art Examination questions.

He has to sincerely thank the many kind friends who have rallied to his help in the preparation of this work, and especially Mr. J. McF. Johnston, for reading over the manuscript, and for the proof of Tchebycheff's rule with two ordinates.

He has also to acknowledge with thanks permission from the Controller of H.M. Stationery Office to reproduce the sheet of data supplied to examination students, and also the examination paper in Naval Architecture for 1904.

MUNICIPAL TECHNICAL INSTITUTE,
BELFAST,
January, 1905.

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NAVAL ARCHITECTURE

CHAPTER I.

ON MATHEMATICS.

The science of Naval Architecture is so dependent on mathematics that a thorough knowledge of this subject is absolutely essential, if the study of naval architecture is to be at all complete, and the student would be well advised to take both subjects concurrently. A brief epitome at this stage of what mathematics are in frequent use throughout the book will be found convenient.

Fractions.—If an apple is cut into four equal portions, any one portion is "a fourth" of an apple; any two portions, "two-fourths;" any three portions, "three-fourths." The terms "a fourth," "two-fourths," "three-fourths" are *fractions* or *fractional numbers.* They are expressed as follows:—

One-fourth, $\frac{1}{4}$
Two-fourths, $\frac{2}{4}$
Three-fourths, $\frac{3}{4}$

In the same way there are twelve inches to every foot. One inch, then, is one-twelfth of a foot, or $\frac{1}{12}$; five inches are $\frac{5}{12}$ of a foot, and so on. Six inches are $\frac{6}{12}$ of a foot, or, as it is more commonly expressed, $\frac{1}{2}$ a foot. We now arrive at an important point, for we see that $\frac{1}{2} = \frac{6}{12}$. That is, the top and bottom number have been multiplied by six, but the *fraction* is no greater. Similarly, $\frac{1}{2} = \frac{5}{10} = \frac{50}{100} = \frac{500}{1000}$. The number above the line is called the "numerator," and that below the line the denominator. The fractions $\frac{5}{10}$, $\frac{7}{100}$, $\frac{9}{1000}$ all have 10, or a power of 10, for a denominator. These fractions may be written in a more convenient form; thus—

$$\begin{aligned} \tfrac{5}{10} &= 0{\cdot}5 \\ \tfrac{7}{100} &= 0{\cdot}07 \\ \tfrac{9}{1000} &= 0{\cdot}009 \end{aligned}$$

and the fractions are now called "point" 5, "point" 07, "point" 009. Note that where there is one 0 in the denominator there is one figure to the right of the point. When there are three zeros in the denominator, there are three figures to the right of the point.

Adding these figures up, the rule is to keep the points below each other, as follows:—

$$\begin{array}{l} 0{\cdot}5 \\ 0{\cdot}07 \\ 0{\cdot}009 \\ \hline 0{\cdot}579 \end{array} \; \textit{Ans.}\text{; or } \tfrac{579}{1000}$$

Similarly—

$$\begin{array}{l} 0{\cdot}7 \\ 0{\cdot}89 \\ 0{\cdot}9 \\ \hline 2{\cdot}49 \end{array} \; \textit{Ans.}\text{; or } 2\tfrac{49}{100}$$

We saw that $\frac{5}{10}$ (or ·5) was the same as $\frac{50}{100}$ (or ·50).

A 0 at the end of a decimal does not alter its value. 0·05, however, alters the decimal, and its value becomes $\frac{5}{100}$.

To multiply decimals the rule is to proceed as for whole numbers, but the answer must have as many figures to the right of the point as there were of the figures being multiplied together. For example—

Multiply 0·57 by 0·242.

$$\begin{array}{r} 0{\cdot}252 \\ 0{\cdot}57 \\ \hline 1764 \\ 1260 \\ \hline 0{\cdot}14364 \end{array} \; \textit{Ans.}$$

In 0·252 there are three figures to the right of the point; in

0·57 there are two. In the answer, therefore, there must be five figures to the right of the point.

Again, multiply 0·21 by 0·42.

$$\begin{array}{r} 0{\cdot}42 \\ \underline{0{\cdot}21} \\ 42 \\ \underline{84} \\ {\cdot}0882 \end{array}\ \textit{Ans.}$$

In this case there must be four figures to the right of the decimal place. As there are only three in the answer, we complete it by adding a zero immediately after the point.

To divide by decimals we proceed almost as for whole numbers.

Example—

Divide 0·05 by 0·008.

0·05 = 0·05000, so that the question is: Divide 0·05000 by 0·008. In both cases shift the decimal point three places to the right. We now have 50·000 to be divided by 8.

$$\begin{array}{l} 8)50{\cdot}000(6{\cdot}25\ \textit{Ans.} \\ \underline{48} \\ 20 \\ \underline{16} \\ 40 \\ \underline{40} \end{array}$$

Note that as soon as we begin to carry down one of the decimal places, we put the decimal point in our answer.

Area and Volume.—Area is the multiple of any two dimensions. Volume is the multiple of three dimensions. Area is expressed in square inches, square feet, or square yards. Volume is expressed in cubic inches, cubic feet, or cubic yards. We speak of the area or surface of a deck; and of the volume or bulk of a hold. The areas of regular figures, such as squares, rectangles, triangles, and circles, may be at once found as follows:—

Area of square = length × breadth
„ rectangle = length × breadth
„ triangle = base × $\frac{1}{2}$ height
„ circle = diameter^2 × 0·7854
Surface of sphere = radius × 12·56 radius

A trapezoid is a figure, the area of which it is more difficult to determine.

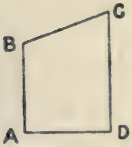


FIG. 1.

AB and DC are of unequal length, but at right angles to the base AD. Take the mean height of AB and DC, which is found by adding them together and dividing them by 2. Multiply this mean height by the base AD. The result will be the area of the figure. Assume AD = 5 feet, AB = 6 feet, DC = 8 feet.

$$\text{Area of trapezoid} = \frac{6+8}{2} \times 5$$
$$= 7 \times 5$$
$$= 35 \text{ square feet}$$

The volume of a regular body, such as a cube or rectoid, is the area of one side or end multiplied by its height.

Volume of cube = area of square × height
Volume of rectangular solid or rectoid = area of rectangle × height
Volume of cylinder = area of circle × height
Volume of cone = area of base by $\frac{1}{3}$ height
Volume of sphere = radius × radius × 4·19 radius
or = diameter × diameter × 0·523 diameter

Equations (for Senior Students).—If we state that $x = 3$ we state an equation, because the sign = (equal to) binds the letter x and the number 3. This equation may be stated in numerous ways; *e.g.*—

$$2x = 6$$
$$x + x = 6$$
$$x = \tfrac{6}{2}$$
$$\text{or } \frac{x}{1} = \tfrac{6}{2}$$

In this case we can get rid of the fractions by multiplying across, *i.e.* multiply the denominator on the one side by the numerator on the other side. Multiply the x by the 2 and the 6 by the 1. We have—

$$2x = 6\text{; and of course}$$
$$x = 3$$

The letter x may have any value.

Assuming $x = 4$, then—

$$2x - 3 = 5$$
$$\frac{5x + 4}{8} = 3$$

x^2, x^3, x^4 are called involutes of x, because they are powers of x: the square of x, the cube of x, the fourth power of x.

$\sqrt[2]{x}$, $\sqrt[3]{x}$, $\sqrt[4]{x}$ are called evolutes of x, because they are roots of x: the square root, the cube root, and the fourth root. To solve an equation is to determine what value x has in the equation.

$$5x - 3 = 4x + 2$$
$$\therefore 5x - 4x = 2 + 3$$
$$\therefore x = 5$$

Note that in changing sides we also change signs, positive becomes negative, and *vice versâ.*

$$\frac{x + 3}{2} = \frac{3x + 4}{2x}$$
$$(x + 3) \times 2x = (3x + 4) \times 2$$
$$2x^2 + 6x = 6x + 8$$
$$2x^2 + 6x - 6x = 8$$
$$2x^2 = 8$$
$$x^2 = 4$$
$$x = 2$$

Indices and Surds.—The letter or sign which shows to what power any quantity is involved is the index of that quantity. The plural of "index" is "indices."

$$A^4,\ A^{16-3},\ A^{m+n},\ A^{x+y-3}$$

These factors of "A" are indices.

1. $$A^2 \times A^3 = A^{2+3} = A^5$$
2. $$A^2 \times A^3 \times A^5 = A^{2+3+5} = A^{10}$$
3. $$A^5 \div A^2 = A^{5-2} = A^3$$
4. $$(A^5)^2 = A^{5\times 2} = A^{10}$$
5. $$A^{\frac{5}{3}} \times A^{\frac{4}{3}} = A^{\frac{5+4}{3}} = A^{\frac{9}{3}} = A^3$$
6. $$A^{\frac{4}{3}} = \sqrt[3]{A^4}$$
7. $$4^{\frac{3}{2}} = \sqrt{4^3} = \sqrt{64} = 8$$

If the root of any quantity cannot be exactly determined, that root is a surd.

Thus $\sqrt{2}$; $\sqrt[3]{5}$ are surds.

But these may also be expressed as indices, thus $2^{\frac{1}{2}}$, $5^{\frac{1}{3}}$. And speaking generally, surds may always be changed to fractional indices.

1. $$\sqrt[3]{5^6} = 5^{\frac{6}{3}} = 5^2 = 25$$
2. $$3 = \sqrt{9} = \sqrt[3]{27} = \sqrt[4]{81}$$
3. $$\sqrt[3]{5} = (5)^{\frac{1}{3}} = (5)^{\frac{3}{9}} = \sqrt[9]{5^3} = \sqrt[9]{125}$$

Multiplication of surds:

1. Surds isobasic—

$$\begin{aligned}\sqrt[5]{2} \times \sqrt[3]{2} = 2^{\frac{1}{5}} \times 2^{\frac{1}{3}} &= 2^{\frac{1}{5}+\frac{1}{3}}\\ &= 2^{\frac{8}{15}}\\ &= \sqrt[15]{2^8}\end{aligned}$$

2. Surds equiradical—

$$\sqrt[5]{2} \times \sqrt[5]{3} = \sqrt[5]{6}$$

3. Surds neither isobasic nor equiradical—

$$\begin{aligned}\sqrt[3]{2} \times \sqrt[2]{3} &= \sqrt[6]{4} \times \sqrt[6]{27}\\ &= \sqrt[6]{108}\end{aligned}$$

Logarithms.—If $A^x = 16$, then x is the logarithm of 16 to the base A.

1. $2^3 = 8$, $\therefore$ 3 is log of 8 to base 2.

2. $10^1 = 10$; $10^2 = 100$; $10^3 = 1000$; $\therefore$ 1, 2, and 3 are logs of 10, 100, and 1000 to base 10.

The common system of logs are to base 10.

$$10^3 = 1000, \therefore \log 1000 = 3$$
$$2432 \text{ is greater than } 10^3$$

but it is less than 10^4, therefore as the log is the power of 10, which gives 2432, the log in this case is more than 3 and less than 4.

It is 3 + a fraction (say, 0·386). This 3 is the "characteristic" of the log. The fraction is the "mantissa." The log would be written 3·386. In the tables, all that would be given would be the decimal parts, as the whole number (3) is governed by the number of digits in 2432 in this case.

The rule is that the log of any number is what is given in the tables as a decimal or mantissa, + for the characteristic one less than the number of digits.

$$\begin{aligned} \text{log of } 24364 &= 4{\cdot}\ \ldots\ldots \\ 24 &= 1{\cdot}\ \ldots\ldots \\ 2 &= 0{\cdot}\ \ldots\ldots \end{aligned}$$

In the log of a decimal the characteristic is one more than the number of ciphers or zeros in the number, but with the negative sign above. Thus—

$$\begin{aligned} \text{log of } 0{\cdot}2 &= \bar{1}{\cdot}\ \ldots\ldots \\ 0{\cdot}02 &= \bar{2}{\cdot}\ \ldots\ldots \\ 0{\cdot}002 &= \bar{3}{\cdot}\ \ldots\ldots \end{aligned}$$

Assume that $\bar{3}{\cdot}4625$ is a log. To divide this we must put it in another form. Thus—

$$\begin{aligned} \tfrac{1}{5}(\bar{3}{\cdot}4625) &= \tfrac{1}{5}(\bar{5} + 2{\cdot}4625) \\ &= \bar{1}{\cdot}4925 \end{aligned}$$

Remember that the negative sign only applies to the characteristic.

Find the value of $\sqrt[3]{392}$.

Given log 7 = 845, log 2 = 301, log 721 = 8643.

$$\begin{aligned} \log \sqrt[3]{392} &= \tfrac{1}{3} \log 392 \ (392 = 7 \times 7 \times 2 \times 2 \times 2) \\ &= \tfrac{1}{3} \log 7 + \log 7 + \log 2 + \log 2 + \log 2 \\ &= \tfrac{1}{3}(0{\cdot}845 + 0{\cdot}845 + 0{\cdot}301 + 0{\cdot}301 + 0{\cdot}301) \\ &= \tfrac{1}{3}(2{\cdot}593) = 0{\cdot}8643 \end{aligned}$$

Or given log 392 = 593.

$$\begin{aligned}\log \sqrt[3]{392} &= \tfrac{1}{3}\log 392\\ &= \tfrac{1}{3}\, 2{\cdot}593\\ &= 0{\cdot}8643\end{aligned}$$

But 8643 is mantissa of log, and as the log has point for its characteristic, it follows that the number will have one cipher less than this, which is 1· (point). Log 721 was given at top = 8643.

$\therefore$ Answer is 7·21

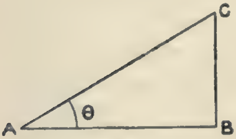


FIG. 2.

Trigonometry. — In a right-angled triangle the relations of certain sides to each other have been given definite names in conjunction with any of the two angles other than the right angle. Thus—

$$\text{Sine } \theta = \frac{BC}{AC}$$

$$\text{Cosine } \theta = \frac{AB}{AC}$$

$$\text{Tangent } \theta = \frac{BC}{AB}$$

$$\text{Cotangent } \theta = \frac{AB}{BC}$$

$$\text{Secant } \theta = \frac{AC}{AB}$$

$$\text{Cosecant } \theta = \frac{AC}{CB}$$

1. The versed sine = unity − cosine
2. Co-versed sine = unity − sine
3. $\text{Sine}^2 + \cos^2 = 1$
4. $\text{Sec}^2 = \tan^2 + 1$
5. $\text{Cosec}^2 = \text{cotan}^2 + 1$
6. $\text{Tan} = \dfrac{\sin}{\cos}$
7. $\text{Cotan} = \dfrac{\cos}{\sin}$
8. $\text{Sec} = \dfrac{1}{\cos}$

9. Cosec $= \frac{1}{\text{sin}}$

10. Cotan $= \frac{1}{\text{tan}}$

Circular Measure.—In a right angle there are 90 equal parts, or degrees. In measuring angles the unit employed is the degree. With centre O and rad. OA, describe an arc AB. Draw any radius OB. Then—

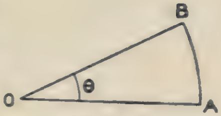


FIG. 3.

$$\text{Circular measure of } \theta = \frac{\text{AB}}{\text{OA}} = \frac{\text{arc}}{\text{radius}}$$

$$\text{Circular measure of } 360 = \frac{\text{circumference}}{\text{radius}} = \frac{2\pi\text{R}}{\text{R}} = 2\pi$$

The circular measure of any angle is the number of degrees it contains $\times \frac{\pi}{180}$. The unit of circular measure is an angle which is subtended at the centre of a circle by an arc = the radius of that circle, and—

$$= \frac{2 \text{ right angles}}{\pi} = \frac{180}{3{\cdot}1416} = 57{\cdot}29^\circ$$

$$\text{Area of a circle} = \frac{\text{circumference}}{\text{radius}} \times \frac{\text{radius}^2}{2}$$

$$= \text{circular measure} \times \frac{\text{R}^2}{2}$$

CHAPTER II.

ON AREAS AND CENTRES OF GRAVITY OF CURVILINEAR FIGURES.

In Naval Architecture there are in general use four different methods of obtaining the areas of plane figures bounded on one side by a curve. The methods may be stated as follows:—

1. Trapezoidal rule.
2. Simpson's first rule.
3. Simpson's second rule.
4. The $\frac{5}{8}$ rule, or Simpson's third rule.

The formulas employed are—

1. $$\text{Area} = \text{CI}\left(\frac{a}{2} + b + c + d + \;.\;.\;.\;.\;\frac{z}{2}\right)$$

Introducing half-ordinates, say Δa—

$$\text{Area} = \text{CI}\left(\frac{a}{4} + \frac{\Delta a}{2} + \tfrac{3}{4}b + c + \;.\;.\;.\;.\;\frac{z}{2}\right)$$

2. $$\text{Area} = \tfrac{1}{3}\text{CI}(a + 4b + 2c + 4d + 2e + 4f + g)$$

Introducing half-ordinates, say Δa, Δb—

$$\text{Area} = \tfrac{1}{3}\text{CI}\left(\frac{a}{2} + 2\Delta a + b + 2\Delta b + 1\tfrac{1}{2}c + 4d + e\right)$$

3. $$\text{Area} = \tfrac{3}{8}\text{CI}(a + 3b + 3c + d)$$

4. $$\text{Area} = \tfrac{1}{12}\text{CI}(5a + 8b - c)$$

$$\text{or} = \text{CI}(\tfrac{5}{12}a + \tfrac{13}{12}b + c + d\;.\;.\;.\;.\;x + \tfrac{7}{12}y - \tfrac{1}{12}z)$$

Trapezoidal Rule.—The figure ABCD is a trapezoid. The dotted line AX is parallel to DC, making figure AXCD a rectangle.

$$\begin{aligned}
\text{Area of AXCD} &= \text{DC (or } y\text{) multiplied by CX or DA}\\
\text{area of ABX} &= \text{AX (or } y\text{) multiplied by } \tfrac{1}{2}\text{BX}\\
\therefore \text{area of ABCD} &= y \times \text{DA} + y \times \tfrac{1}{2}\text{BX}\\
&= y \times (\tfrac{1}{2}\text{DA} + \tfrac{1}{2}\text{DA}) + y \times \tfrac{1}{2}\text{BX}\\
&= y \times (\tfrac{1}{2}\text{DA} + \tfrac{1}{2}\text{CX}) + y \times \tfrac{1}{2}\text{BX}\\
&= y \times (\tfrac{1}{2}\text{DA} + \tfrac{1}{2}\text{CX} + \tfrac{1}{2}\text{BX})\\
&= y \times (\tfrac{1}{2}\text{DA} + \tfrac{1}{2}\text{CB})
\end{aligned}$$

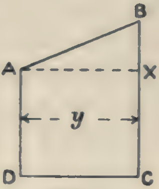


FIG. 4.

Assume now a number of trapezoids adjoining each other, having their bases y all equal.

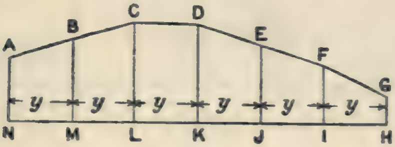


FIG. 5.

This figure approaches very closely to a curvilinear figure. Taking each of the trapezoids in order, we find from previous proof—

$$\begin{aligned}
\text{Area ABMN} &= y \times (\tfrac{1}{2}\text{AN} + \tfrac{1}{2}\text{BM})\\
\text{,, BCLM} &= y \times (\tfrac{1}{2}\text{BM} + \tfrac{1}{2}\text{CL})\\
\text{,, CDKL} &= y \times (\tfrac{1}{2}\text{CL} + \tfrac{1}{2}\text{DK})\\
\text{,, DEJK} &= y \times (\tfrac{1}{2}\text{DK} + \tfrac{1}{2}\text{EJ})\\
\text{,, EFIJ} &= y \times (\tfrac{1}{2}\text{EJ} + \tfrac{1}{2}\text{FI})\\
\text{,, FGHI} &= y \times (\tfrac{1}{2}\text{FI} + \tfrac{1}{2}\text{GH})
\end{aligned}$$

The addition of all these trapezoids is the area of the whole figure. Therefore, area of whole figure $= y \times (\tfrac{1}{2}\text{AN} + \tfrac{1}{2}\text{BM} + \tfrac{1}{2}\text{BM} + \tfrac{1}{2}\text{CL} + \tfrac{1}{2}\text{CL} + \tfrac{1}{2}\text{DK} + \tfrac{1}{2}\text{DK} + \tfrac{1}{2}\text{EJ} + \tfrac{1}{2}\text{EJ} + \tfrac{1}{2}\text{FI} + \tfrac{1}{2}\text{FI} + \tfrac{1}{2}\text{GH})$

$$= y \times (\tfrac{1}{2}\text{AN} + \text{BM} + \text{CL} + \text{DK} + \text{EJ} + \text{FI} + \tfrac{1}{2}\text{GH}).$$

The rule, then, may be stated thus: To find the area of a plane figure by the trapezoidal method, divide the base into any number of equidistant spaces. Add all the ordinates together except the first and last, of which add ½ the sum. The result multiplied by the common interval = area.

This area is only approximate, and the error is shown by the shaded part in these two figures (6 and 7). In figure A the area found will be less than the actual area. In figure B the area found will be more than the actual area.

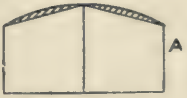


Fig. 6.

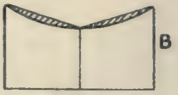


Fig. 7.

Where a curve turns abruptly half-ordinates are sometimes introduced.

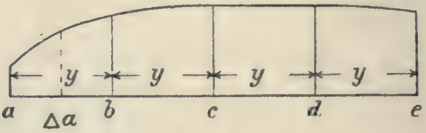


Fig. 8.

The half-ordinate Δa is here introduced, and the area of the figure $= y \times \left(\frac{a}{4} + \Delta a^2 + \tfrac{3}{4}b + c + d + \frac{e}{2}\right)$. In an irregular curve, as in Fig. 9, considerable error might arise. This error is mitigated by putting an ordinate at C, and treating figure as two separate curves.

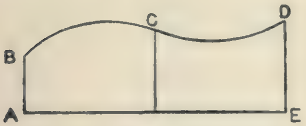


Fig. 9.

Simpson's First Rule.—It is this rule which is most extensively used in ship calculations, both from its ease in handling and the correctness of the result. The mathematical basis for this method is that the curve is a parabola of the second order, and the area of a segment of the curve is found by multiplying the base by ⅔ of its deflection.

In Figs. 10 and 11 the deflection is XO and the base is DC. The formula for finding the area of either of the figures is as follows:—

$$\text{Area AXBCD} = \tfrac{1}{3}y(\text{AD} + 4\text{XE} + \text{BC})$$

Let ABCD be a curvilinear figure.
Required to find its area.

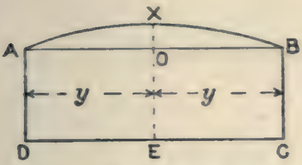


FIG. 10.

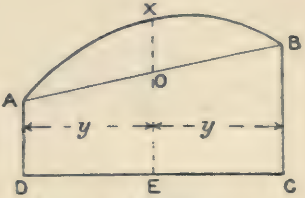


FIG. 11.

Construction.—Bisect DC in E, and erect a perpendicular meeting curve in X. Join AB.

Statement.—Area ABCD $= \frac{1}{3}y(\text{AD} + 4\text{XE} + \text{BC})$.

Approximate proof.

$$\left.\begin{array}{l}\text{Area of trapezoid}\\ \quad\text{ABCD}\end{array}\right\} = \frac{\text{AD} + \text{BC}}{2} \times 2y$$

$$\left.\begin{array}{l}\text{area of segment}\\ \quad\text{AXB}\end{array}\right\} = \tfrac{2}{3}\text{XO} \times 2y$$

$$\text{but OE} = \frac{\text{AD} + \text{BC}}{2}$$

$$\text{and XO} = \text{XE} - \text{OE}$$

$$= \text{XE} - \frac{\text{AD} + \text{BC}}{2}$$

$$\left.\begin{array}{l}\therefore\text{area of segment}\\ \quad\text{AXB}\end{array}\right\} = \tfrac{2}{3}\left(\text{XE} - \frac{\text{AD} + \text{BC}}{2}\right) \times 2y$$

$$\left.\begin{array}{l}\text{and area of whole}\\ \quad\text{figure}\end{array}\right\} = \frac{\text{AD} + \text{BC}}{2} \times 2y + \tfrac{2}{3}\left(\text{XE} - \frac{\text{AD} + \text{BC}}{2}\right) \times 2y$$

$$= \frac{\text{AD} + \text{BC}}{2} \times 2y + \left(\frac{2\text{XE}}{3} - \frac{2\text{AD} + 2\text{BC}}{6}\right) \times 2y$$

$$= 2y\left(\frac{\text{AD} + \text{BC}}{2} + \frac{2\text{XE}}{3} - \frac{2\text{AD} + 2\text{BC}}{6}\right)$$

$$= 2y\frac{(3\text{AD} + 3\text{BC} + 4\text{XE} - 2\text{AD} - 2\text{BC})}{6}$$

$$= 2y\frac{(\text{AD} + 4\text{XE} + \text{BC})}{6}$$

$$= y\frac{(\text{AD} + 4\text{XE} + \text{BC})}{3}$$

$$= \tfrac{1}{3}y(\text{AD} + 4\text{XE} + \text{BC})$$

In Fig. 12 the base DK has been divided into four equal spaces at E, C, and L, and perpendiculars erected at these spots.

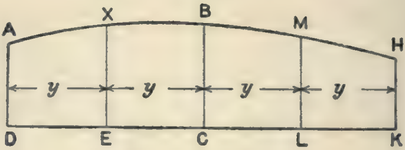


FIG. 12.

$$\begin{aligned}\text{Area ABCD} &= \tfrac{1}{3}y(AD + 4XE + BC)\\ \text{,, BHKC} &= \tfrac{1}{3}y(BC + 4ML + HK)\\ \text{area whole figure} &= \tfrac{1}{3}y(AD + 4XE + BC + BC + 4ML + HK)\\ &= \tfrac{1}{3}y(AD + 4XE + 2BC + 4ML + HK)\end{aligned}$$

So that with five ordinates the multipliers are 1, 4, 2, 4, 1. Similarly, the multipliers for seven ordinates are 1, 4, 2, 4, 2, 4, 1. If these ordinates are numbered consecutively, it will be found that the even-numbered ordinates are multiplied by 4, and the odd-numbered ordinates by 2. The rule is: To find the area of a curvilinear figure by Simpson's first rule, divide the base into any even number of equidistant spaces. To four times the sum of the even ordinates add twice the sum of the odd ordinates, except the first and last. To the total add the first and last, and multiply the result by one-third of the common interval between the ordinates. In a broken curve, as in Fig. 9, considerable error might arise. This is obviated by introducing half-ordinates. Simpson's multipliers are made up of a series of 1, 4, 1. Thus—

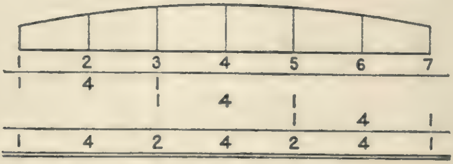


FIG. 13.

Introducing half-ordinates, then, the multipliers would be—

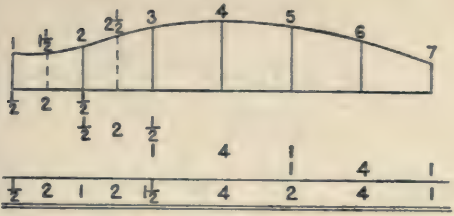


FIG. 14.

The beginning and end of each of these series are the "points of discontinuity."

We may find the area of a curve such as figure provided the break of the curve is at a point of discontinuity, as it is in Fig. 15.

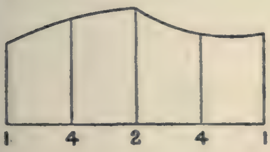


FIG. 15.

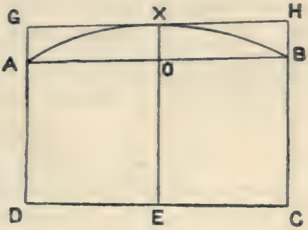


FIG. 16.

Second Proof of Simpson's First Rule Approximate.—In curvilinear figure AXBCD the base DC is bisected at E, and EX erected perpendicular to DC. AB is joined. Through X the line GH is drawn parallel to AB, and DA and CB are produced to meet it.

Curve AXB being a parabola, the area of the segment AXB $= \frac{2}{3}$ area of ▱ AGHB (or parallelogram AGHB).

$$\mathrm{EO} = \frac{\mathrm{AD} + \mathrm{BC}}{2}$$

$$\begin{aligned} \mathrm{XO} &= \mathrm{XE} - \mathrm{EO} \\ &= \mathrm{XE} - \frac{\mathrm{AD} + \mathrm{BC}}{2} \end{aligned}$$

$$\begin{aligned} \mathrm{AXB} &= \tfrac{2}{3} \text{ area ▱ AGHB} \\ &= \tfrac{2}{3}\mathrm{DC} \times \mathrm{AG} \text{ (Euclid)} \\ &= \tfrac{2}{3}\mathrm{DC} \times \mathrm{XO} \\ &= \tfrac{2}{3}2y \times \mathrm{XO} \\ &= \tfrac{4}{3}y \times \mathrm{XO} \end{aligned}$$

$$= \tfrac{4}{3}y\left(\text{XE} - \frac{\text{AD} + \text{BC}}{2}\right)$$

$$= \tfrac{4}{3}y\left(\text{XE} - \frac{\text{AD}}{2} - \frac{\text{BC}}{2}\right)$$

area of trapezoid ABCD $\left.\right\} = 2y\left(\frac{\text{AD}}{2} + \frac{\text{BC}}{2}\right)$

∴ area of whole figure AXBCD $\left.\right\} = 2y\left(\frac{\text{AD}}{2} + \frac{\text{BC}}{2}\right) + \tfrac{4}{3}y\left(\text{XE} - \frac{\text{AD}}{2} - \frac{\text{BC}}{2}\right)$

$$= y(\text{AD} + \text{BC}) + \tfrac{4}{3}y\left(\text{XE} - \frac{\text{AD}}{2} - \frac{\text{BC}}{2}\right)$$

$$= \tfrac{1}{3}y(3\text{AD} + 3\text{BC} + 4\text{XE} - 2\text{AD} - 2\text{BC})$$

$$= \tfrac{1}{3}y(\text{AD} + 4\text{XE} + \text{BC})$$

Example.—Find the area of a plane curvilinear figure whose equidistant ordinates have the following breadths: 5, 7, 9, 10, 10, 9, 7 feet respectively. The common interval or distance between the ordinates is 6 feet. This calculation is usually wrought out in tabular form as follows:—

No. of ordinates.	Breadths of ordinates.	Simpson's multipliers.	Functions of ordinates.
1	5	1	5
2	7	4	28
3	9	2	18
4	10	4	40
5	10	2	20
6	9	4	36
7	7	1	7
		Sum	= 154

But by rule this sum has to be again multiplied by one-third common interval. As the common interval is 6 feet, one-third of it will be 2 feet.

Area of curve then = 154 × 2
= 308 square feet

Simpson's Second Rule.—The mathematical basis for this rule is that the curve is a parabola of the third order.

Example.—Find the area of a plane curvilinear figure whose equidistant ordinates have the following lengths: 5, 7, 9, 10, 10, 9, 7, 4, 2, 1 feet respectively. The common interval is

8 feet. The calculation is wrought out in tabular form as follows:—

No. of ordinates.	Breadths of ordinates.	Simpson's multipliers.	Functions of ordinates.
1	5	1	5
2	7	3	21
3	9	3	27
4	10	2	20
5	10	3	30
6	9	3	27
7	7	2	14
8	4	3	12
9	2	3	6
10	1	1	1
		Sum	= 163

But by rule this sum has to be again multiplied by three-eighths of the common interval. As the common interval is 8 feet, three-eighths of it would be 3 feet.

$$\begin{aligned}\text{Area of curve then} &= 163 \times 3\\ &= 489 \text{ square feet}\end{aligned}$$

The Five-eight Rule.—The mathematical basis for this rule is that the curve is a parabola of the second order.

In Fig. 16, AXBCD, by Simpson's first rule—

$$\text{Area} = \tfrac{1}{3}y(\text{AD} + 4\text{XE} + \text{BC})$$

The five-eight rule says—

$$\begin{aligned}\text{Area AXED} &= \tfrac{1}{12}y(5\text{AD} + 8\text{XE} - \text{BC})\\ \text{and area XBCE} &= \tfrac{1}{12}y(5\text{BC} + 8\text{XE} - \text{AD})\end{aligned}$$

Adding these two areas, we get the area of the whole figure, and this is—

$$\begin{aligned}&= \tfrac{1}{12}y(5\text{AD} + 8\text{XE} - \text{BC} + 5\text{BC} + 8\text{XE} - \text{AD})\\ &= \tfrac{1}{12}y(4\text{AD} + 16\text{XE} + 4\text{BC})\\ &= \tfrac{1}{3}y(\text{AE} + 4\text{XE} + \text{BC})\end{aligned}$$

Note that the area found is between two ordinates only, although we require three ordinates to find this.

For example—

$$\text{AXED} = \tfrac{1}{12}y(5\text{AD} + 8\text{XE} - \text{BC})$$

The area found is that between ordinates AD and XE. We take one-twelfth of the interval, and multiply it by five times AD and eight times XE. But this would give too great an area, so that to get the answer correctly one-twelfth of BC is deducted.

Approximate proof of five-eight rule.

$$\begin{aligned}
\text{Area AOED} &= y\left(\frac{\text{AD}}{2} + \frac{\text{OE}}{2}\right)\\
&= y\left(\frac{\text{AD}}{2} + \frac{\text{AD} + \text{BC}}{4}\right)\\
\text{area AXO} &= \tfrac{2}{3}\,\text{AXGO}\\
&= \tfrac{2}{3}y\left(\text{XE} - \frac{\text{AD} + \text{BC}}{2}\right)\\
&= \tfrac{2}{3}y\frac{(2\text{XE} - \text{AD} - \text{BC})}{2}\\
&= \tfrac{1}{3}y(2\text{XE} - \text{AD} - \text{BC})\\
&= y\frac{(2\text{XE} - \text{AD} - \text{BC})}{3}\\
\text{area AXED} &= \text{AOED} + \text{AXO}\\
&= y\left(\frac{\text{AD}}{2} + \frac{\text{AD} + \text{BC}}{4}\right) + y\left(\frac{2\text{XE} - \text{AD} - \text{BC}}{3}\right)\\
&= y\left(\frac{\text{AD}}{2} + \frac{\text{AD}}{4} + \frac{\text{BC}}{4} + \frac{2\text{XE}}{3} - \frac{\text{AD}}{3} - \frac{\text{BC}}{3}\right)\\
&= y\frac{(6\text{AD} + 3\text{AD} + 3\text{BC} + 8\text{XE} - 4\text{AD} - 4\text{BC})}{12}\\
&= y\frac{(5\text{AD} + 8\text{XE} - \text{BC})}{12}\\
&= \tfrac{1}{12}y(5\text{AD} + 8\text{XE} - \text{BC})
\end{aligned}$$

The five-eight rule extended and simplified.

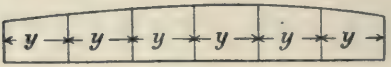


FIG. 17.

$$\tfrac{1}{12}y\left\{\begin{array}{ccccccc}
5 & 8 & -1 & & & & \\
 & 5 & 8 & -1 & & & \\
 & & 5 & 8 & -1 & & \\
 & & & 5 & 8 & -1 & \\
 & & & & 5 & 8 & -1
\end{array}\right.$$

$$\tfrac{1}{12}y\;(5 \quad 13 \quad 12 \quad 12 \quad 12 \quad 7 \quad -1)$$

$$y\;(\tfrac{5}{12};\ \tfrac{13}{12};\ 1;\ 1;\ 1;\ \tfrac{7}{12};\ -\tfrac{1}{12})$$

We can find the area of a curvilinear figure with *any* number of equidistant ordinates by taking $\frac{5}{12}$, $\frac{13}{17}$, and $\frac{7}{12}$ of the first, second, and second last ordinates respectively, and once all the rest. From this total sum deduct $\frac{1}{12}$ of the ordinate immediately beyond the area required, and multiply the remainder by the common interval.

The five-eight rule and **Simpson's first rule** may be combined when ordinates given do not suit Simpson's first rule.

For example—

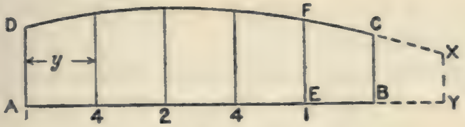


FIG. 18.

The area ABCD cannot be found by Simpson's rule, but area AEFD may be so found. By five-eight rule area EBCF may be found.

$$\text{Area AEFD} = \tfrac{1}{3}y\,(1,\ 4,\ 2,\ 4,\ 1)$$

$$\text{,, \quad EBCF} = \tfrac{1}{12}y\,(5,\ 8, -1)$$

$$\text{Combining the two} = y\,(\tfrac{1}{3},\ \tfrac{4}{3},\ \tfrac{2}{3},\ \tfrac{4}{3},\ \tfrac{1}{3} + \tfrac{5}{12},\ \tfrac{8}{12}, -\tfrac{1}{12})$$

$$= y\,(\tfrac{1}{3},\ \tfrac{4}{3},\ \tfrac{2}{3},\ \tfrac{4}{3},\ \tfrac{9}{12},\ \tfrac{8}{12}, -\tfrac{1}{12})$$

$$= \tfrac{1}{3}y(1,\ 4,\ 2,\ 4,\ \tfrac{9}{4},\ 2, -\tfrac{1}{4})$$

The rules revised and certain points noted in the working of same.

The trapezoidal rule can be applied to a curve with any number of equidistant ordinates.

Simpson's first rule can only be applied to a curve which has been divided into an even number of equal spaces. In this case there will be an odd number of ordinates. Thus a curve divided into two equal spaces will have three ordinates—the two end ordinates and the middle ordinate.

Simpson's second rule can only be applied to a curve which has been divided into a number of equal spaces divisible by 3.

The five-eight rule can be applied to a curve with any number of equidistant ordinates, provided we have an ordinate beyond the area required.

Where the area of a deck, etc., is required, and only half-ordinates (or half-breadths) are given, the answer must be multiplied by 2. All the rules apply equally well to vertical and horizontal ordinates. A deck, for instance, would have vertical ordinates.

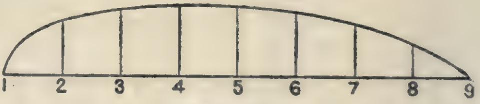


FIG. 19.

A section or half-section of a vessel would have horizontal ordinates, or water-lines.

In this case the common interval would be probably given in inches, say 18 inches. This would be transposed to feet (1·5 feet) before using it. Where a curve changes abruptly, ordinates are sometimes introduced at half the common interval. This is done to secure greater accuracy in the result.

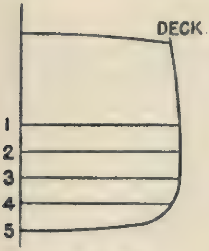


FIG. 20.

On Centres of Gravity of Plane Surfaces.—The centre of gravity of a surface is the point at which the surface would balance, assuming it to have weight, as, for example, a thin steel plate. Thus, if a circular plate was set with its centre on a sharp-pointed stand, the plate would balance, because its centre is also its centre of gravity. This point, the balancing-point, may be found for a surface of any shape. Certain regular figures can have their centres of gravity, or C.G., determined at once without calculation.

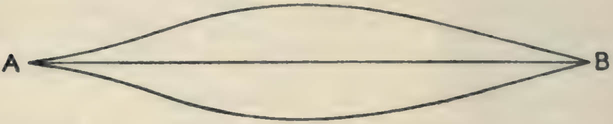


FIG. 21.

In a ship's deck plan or water-plane the C.G. would be at some point along the centre line of the plane. Thus, in Fig. 21 the C.G. will lie in the line AB.

If both the forward and after ends of the plane were alike the C.G. would, of course, be at the middle of the length. When the ends are dissimilar, the mode of procedure is somewhat difficult.

A square and rectangle have their C.G.'s at the intersection of their diagonals. In a triangle, if any two sides are bisected, and lines drawn from these points to the opposite angles, the intersection of these lines is the C.G. of the triangle.

If a long, thin lath is fastened at one end to a table with the other end projecting, say 5 feet beyond the table, and a weight is placed on the lath, first close to the table, and then gradually further away, say 1 foot each time, until the weight is at the extreme end, it will be found that as the weight is shifted outwards, the lath bends down further with every shift. The weight used is the same, but its bending power is obviously greater the further it is from the point of support. This bending value of the weight is called its moment, and the moment is in direct proportion to its distance from the point of support.

Thus, if the weight used was 4 lbs., and it was placed 3 feet from the point of support, its moment would be 4 lbs. by 3 feet = 12 foot-lbs. Now assume the lath to be balanced about the middle of its length and both ends free. If weights of, say, 3 lbs. are placed 2 feet on each side of the balancing-point, the lath will remain level. Now shift one of the weights 1 inch further away, and the rod is immediately inclined towards that side.

The weight has not been increased, but its moment has, and the moment is directly due to its distance from the balancing-point. It is the moment, and not the weight, which has caused the rod to incline. For example: A weight of 1 lb. could be made to balance a weight of 1 ton, if the 1-lb. weight was sufficiently far from the balancing-point that its moment (or weight × distance) was equal to the moment of the ton.

In the same way a number of weights could be arranged on one side to balance the single weight on the other side of the balancing-point, or fulcrum.

Suppose a number of weights, totalling in all, say, 10 lbs., were arranged at different distances along one side of the balancing-point, and it is required to find at what point on the other side a single weight of 10 lbs. will balance the lath. The mode of procedure would be as follows:—

Total moment of various small weights are found thus—

1 lbs. × 5 feet = 5 foot-lbs. moment
3 „ × 4 „ = 12 „ „
2 „ × 6 „ = 12 „ „
4 „ × 9 „ = 36 „ „
Total moment of small weights = 65 „

This means that a moment of 65 foot-lbs. will balance the lath. The moment is the weight multiplied by its distance or lever. The lever or distance is, then, the moment divided by the weight, or 65 foot-lbs. divided by 10 lbs. = 6·5 feet, which is the distance required. In the same way, the balancing-point, or centre of gravity of any number of weights can be found by dividing the sum of the moment by the sum of the weights.

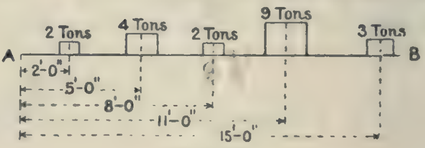


Fig. 22.

Assume the above weights arranged as shown.

Required to find about what point in the length they will balance.

Taking moments from point A—

Sum of moments = 2 tons × 2 feet = 4 foot-tons
+ 4 „ × 5 „ = 20 „
+ 2 „ × 6 „ = 12 „
+ 9 „ × 11 „ = 99 „
+ 3 „ × 15 „ = 45 „
Total weight, 20 „ mts. 180 „

The balancing-point will be the moments divided by the weights = $\frac{180}{20}$ = 9 feet. It is this principle which is used all through Naval Architecture to determine centres of buoyancy and centres of gravity.

Longitudinal Centre of Gravity of a Water-plane or Half Water-plane.—In this case the ordinates LB, MC, ND, etc., take the place of the *weights* we have already been considering. The total length of the plane is, say, 24 feet. The ordinates will therefore be 3 feet apart, because there are eight intervals. But as it is the balancing-point of the whole plane, and not of the several

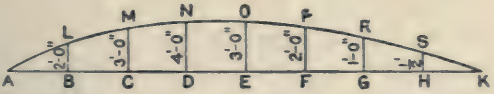


FIG. 23.

ordinates of the plane, that is required, it will be found by dividing the moment of the plane by the area of the plane. Simpson's multipliers, then, must be introduced, and the calculation is arranged in tabular form as follows:—

Ordinates.	Breadths of ordinates.	Simpson's multipliers.	Functions of ordinates.	Levers from A.	Products.
1	0	1	0	0	0
2	2	4	8	3	24
3	3	2	6	6	36
4	4	4	16	9	144
5	3	2	6	12	72
6	2	4	8	15	120
7	1	2	2	18	36
8	0·5	4	2	21	42
9	0	1	0	24	0
		Sum	= 48	Sum	= 474

To get the area of the water-plane the sum of the functions must be multiplied by one-third common interval.

Similarly, to get the sum of the moments, the sum of the products must be multiplied by one-third common interval. The sum of the moments divided by the area will give the centre of gravity.

That is, 474 × $\frac{1}{3}$ common interval divided by 48 × $\frac{1}{3}$ common interval = centre of gravity from the point the levers were taken from. But as both 474 and 48 are multiplied by the same figures, it is usual to ignore this entirely, and the C.G. becomes $\frac{474}{48}$ = 9·875 feet from A.

ANOTHER METHOD.

Ordinates.	Breadths of ordinates.	Simpson's multipliers.	Functions of ordinates.	Levers from middle ordinate.	Product.
1	0	1	0	12	0
2	2	4	8	9	72
3	3	2	6	6	36
4	4	4	16	3	48
5	3	2	6	0	156
6	2	4	8	3	24
7	1	2	2	6	12
8	0·5	4	2	9	18
9	0	1	0	12	0
			48		54

In this case, as the levers have been taken about the middle ordinate, the centre of gravity will also be measured from the middle ordinate, and it will lie towards the side that has the greater sum of products. The excess products will be found by subtracting the lesser from the greater, *i.e.* 156 − 54 = 102.

$\frac{102}{48}$ = 2·125 C.G. from No. 5 ordinate towards No. 1.

But No. 5 ordinate is 12 feet from No. 1 ordinate.

The C.G. from No. 1 = 12 − 2·125 = 9·875 feet.

This is the answer, as already found by the first method.

Instead of using the actual levers of the ordinates, such as 3, 6, 9, 12, 15, etc., feet, the number of the *intervals* from the assumed balancing-point might be taken. The 3-feet lever is one interval away, the 6-feet lever is two intervals away, and so on. The levers now become 0, 1, 2, 3, 4, etc., and the products will, of course, require to be multiplied by the distance apart of the intervals, *i.e.* 3 feet.

The longitudinal C.G. of a curvilinear plane considered by means of elementary strips.

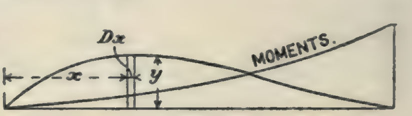


FIG. 24.

In the above figure yDx would be the area of an elementary strip. Its moment about 0 would be—

$$y\mathrm{D}x \times \left(x + \frac{\mathrm{D}x}{2}\right) = xy\mathrm{D}x \times y\frac{(\mathrm{D}x^2)}{2}$$

$$\int xy\mathrm{D}x = \int \text{elementary moments}$$
$$= \text{total moments}$$

Set off a curve of elementary moments, and the area of the curve = total moments. In the curve each ordinate may be assumed to be an elementary strip. The moments may be taken about any ordinate that is a multiple of 1 and 2, but not of 4. The reason for this will be apparent from the accompanying diagram.

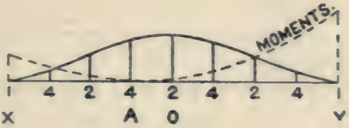


FIG. 25.

Assume that the moment of each ordinate is taken about A. Construct a curve of moments. This curve is really composed of two distinct curves. The area of the curve of moments is the total moment of the plane. This area is the sum of the areas of the two curves. And it is clear that these areas cannot be calculated from the ordinates of either curve. Had the moments been taken from O, the curve of moments would have been divided at O, and the multipliers of the ordinates for that part between O and Y would have been 1, 4, 2, 4, 1, and for that part between O and X, 1, 4, 2, 4, 1. This would have given correct areas for the curves, and consequently a correct total moment for the figure.

The Transverse C.G. of a Curvilinear Plane Figure.—To find this C.G. the work is arranged in tabular form as before.

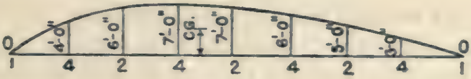


FIG. 26.

	Ordinate.	Simpson's multipliers.	Product.	Ordinate².	Simpson's multipliers.	Product.
1	0	1	0	0	1	0
2	4	4	16	16	4	64
3	6	2	12	36	2	72
4	7	4	28	49	4	196
5	7	2	14	49	2	98
6	6	4	24	36	4	144
7	5	2	10	25	2	50
8	3	4	12	9	4	36
9	0	1	0	0	1	0
			116			2)660 330

$$\frac{330 \times \frac{1}{3}\text{C.I.}}{116 \times \frac{1}{3}\text{C.I.}} = \tfrac{330}{116} = 2{\cdot}8 \text{ feet out}$$

ANOTHER METHOD.

	Ordinate.	Simpson's multipliers.	Product.	Half-ordinate.	Product.
1	0	1	0	0	0
2	4	4	16	2	32
3	6	2	12	3	36
4	7	4	28	3·5	98
5	7	2	14	3·5	49
6	6	4	24	3	72
7	5	2	10	2·5	25
8	3	4	12	1·5	18
9	0	1	0	0	0
			116		330

$$\frac{330 \times \frac{1}{3}\text{C.I.}}{116 \times \frac{1}{3}\text{C.I.}} = \tfrac{330}{116} = 2{\cdot}8 \text{ C.G. out from centre line}$$

This second method has been deduced from the first method. For example, take No. 3 ordinate. By the first method the ordinate was squared and put through S.M., and the sum of the products divided by 2, or—

$$\frac{\text{ordinate} \times \text{ordinate} \times \text{S.M.}}{2} = \begin{cases}\text{ordinate} \times \text{S.M.} \times \frac{1}{2}\text{ ordinate,} \\ \text{which is the second method}\end{cases}$$

Proof of Five-eight Rule (Simpson's Third Rule).—This rule is applicable to any curve whose equation is $y = a_0 + a_1x + a_2x^2$, a being a constant.

The area of an indefinitely narrow strip is ydx;

$$\text{therefore total area of figure} = \int_0^h ydx$$

and this is between the limits h and 0. Substituting value of y, then—

$$\int_0^h (a_0 + a_1x + a_2x^2)dx = \text{area}$$

Integrating— $\left[ax + \frac{1}{2}ax^2 + \frac{1}{3}ax^3\right]_0^h$

Evaluating— $ah + \frac{1}{2}ah^2 + \frac{1}{3}ah^3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (A)$

when $x = 0$, $y = a_0$;
$x = h$, $y = a_0 + a_1h + a_2h^2$;
$x = 2h$, $y = a_0 + 2a_1h + 4a_2h^2$.

Calling these ordinates, y_1, y_2, y_3—

$$\therefore y_1 = a_0$$
$$y_2 = a_0 + a_1h + a_2h^2$$
$$y_3 = a_0 + 2a_1h + 4a_2h^2$$

Solving the equation for a_0, a_1, a_2—

$$a_1h + a_2h^2 = y_2 - y_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$2a_1h + 4a_2h^2 = y_3 - y_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Multiply (1) × 2—

$$2a_1h + 2a_2h^2 = 2y_2 - 2y_1 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and subtract from (2)—

$$2a_2h^2 = y_3 - 2y_2 + y_1$$
$$\therefore a_2 = \frac{1}{2h^2}(y_3 - 2y_2 + y_1) \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Substituting value of a_2 in (1)—

$$a_1h + h^2 \times \frac{1}{2h^2}(y_3 - 2y_2 + y_1) = y_2 - y_1$$
$$= 2a_1h + y_3 - 2y_2 + y_1 - 2y_2 + 2y_1 = 0$$
$$a_1 = \frac{1}{2h}(4y_2 - y_3 - 3y_1)$$

Hence—

$$a_0 = y_1$$
$$a_1 = \frac{1}{2h}(4y_2 - y_3 - 3y_1)$$
$$a_2 = \frac{1}{2h^2}(y_3 - 2y_2 + y_1)$$

Substituting these values of a_0, a_1, and a_2 in equation (A) we get—

$$y_1h + \frac{h}{4}(4y_2 - 3y_1 - y_3) + \frac{h}{6}(y_3 - 2y_2 + y_1)$$
$$= \frac{h}{24}(10y_1 + 16y_2 - 2y_3)$$
$$= \frac{h}{12}(5y_1 + 8y_2 - y_3)$$

and this is the algebraic form of the five-eight rule, h being the common interval, and y_1, y_2, y_3, being the ordinates.

This rule is used to find area of shaded portion of figure, although three ordinates are used; No. 3 being for the purpose of correcting for the curve being convex or concave.

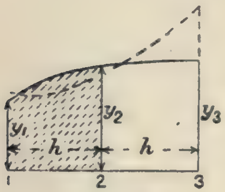


FIG. 27.

Proof of Simpson's First Rule.—There are two methods of doing this:

First by the indirect method.

The equation of the curve referred to the axis is $y = a_0 + a_1x + a_2x^2$; then the area of a narrow strip of length y and breadth $\Delta x = y\Delta x$; and area required between $x = 0$ and $x = 2h$ is the sum of all such strips between these limits.

Now, using the formula of the calculus—

$$\int_0^{2h} y dx$$

or putting in value of y from equation—

$$\int_0^{2h} (a_0 + a_1x + a_2x^2)dx$$

Integrating, and this becomes—

$$\left[a_0x + \tfrac{1}{2}a_1x^2 + \tfrac{1}{3}a_2x^3\right]_0^{2h}$$

which has to be evaluated between the limits, $x = 2h$ and $x = 0$. The expression then becomes—

$$2a_0h + 2a_1h^2 + \tfrac{8}{3}a_2h^3 = \text{area} \quad . \quad . \quad . \quad . \quad (2)$$

The area given by the rule is—

$$\tfrac{1}{3}h(y_1 + 4y_2 + y_3) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\begin{aligned} \text{Now, } y_1 &= a_0 \text{ (see five-eight rule proof)} \\ y_2 &= a_0 + a_1h + a_2h^2 \\ y_3 &= a_0 + 2a_1h + 4a_2h^2 \end{aligned}$$

Substituting these values of y_1, y_2, y_3, in (1)—

$$\begin{aligned} &\tfrac{1}{3}h\{a_0 + 4(a_0 + a_1h + a_2h^2) + a_0 + 2a_1h + 4a_2h^2\} \\ &\quad = \tfrac{1}{3}h(6a_0 + 6a_1h + 8a_2h^2) \end{aligned}$$

$= 2a_0h + 2a_1h^2 + \frac{8}{3}a_2h^3$, and this is the expression (2) above and proves the rule.

Proof of Simpson's First Rule. Second or direct method.—Starting from equation (2) (see first method as shown above), which is—

$$2a_0h + 2a_1h^2 + \tfrac{8}{3}a_2h^3 . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Substituting in this equation the values of a_0, a_1, a_2, which have been already found for five-eight rule, and are as follows:—

$$\begin{aligned} a_0 &= y_1 \\ a_1 &= \frac{1}{2h}(4y_2 - 3y_1 - y_3) \\ a_2 &= \frac{1}{2h^2}(y_3 - 2y_2 + y_1) \end{aligned}$$

Then the equation (3) above becomes—

$$y_12h + \frac{4h^2}{2} \times \frac{1}{2h}(4y_2 - 3y_1 - y_3) + \frac{8h^3}{3} \times \frac{1}{2h^2}(y_3 - 2y_2 + y_1)$$

and this upon reduction becomes—

$$\tfrac{1}{3}h(y_1 + 4y_2 + y_3) = \text{area}$$

and is the expression for Simpson's rule.

Proof of Simpson's Second Rule.—There are also two proofs of this rule, similar methods being adopted to those used in proof of first rule; this rule being intended to apply to a parabolic curve of the third order, the equation of which is—

$$y = a_0 + a_1x + a_2x^2 + a_3x^3$$

The limits of integration are also extended to between

$$x = 3h \text{ and } x = 0;$$

therefore the expression for area is—

$$\int_0^{3h}(a_0 + a_1x + a_2x^2 + a_3x^3)dx$$

Integrating, and it becomes—

$$\left[a_0x + \tfrac{1}{2}a_1x^2 + \tfrac{1}{3}a_2x^3 + \tfrac{1}{4}a_3x^4\right]_0^{3h}$$

Evaluating—

$$3a_0h + 9a_1\frac{h^2}{2} + 9a_2h^3 + \tfrac{81}{4}a_3h^4 \quad . \quad . \quad . \quad (1)$$

Now, by reasoning as in five-eight proof, we get—

$$\begin{aligned} y_1 &= a_0 \\ y_2 &= a_0 + a_1h + a_2h^2 + a_3h^3 \\ y_3 &= a_0 + 2a_1h + 4a_2h^2 + 8a_3h^3 \\ y_4 &= a_0 + 3a_1h + 9a_2h^2 + 27a_3h^3 \end{aligned}$$

If we substitute the above values for y_1, y_2, y_3, y_4, in the expression for Simpson's rule, viz.—

$$\tfrac{3}{8}h(y_1 + 3y^2 + 3y_3 + y_4) = \text{area}$$

we find the result is the same as the expression (1), and proves the rule.

Second or Direct Method of Proving the Rule.—Take the equations—

$$\begin{aligned} y_1 &= a_0 \\ y_2 &= a_0 + a_1h + a_2h^2 + a_3h^3 \\ y_3 &= a_0 + 2a_1h + 4a_2h^2 + 8a_3h^3 \\ y_4 &= a_0 + 3a_1h + 9a_2h^2 + 27a_3h^3 \end{aligned}$$

and solve these for values of a_0, a_1, a_2, and a_3, and substitute these values in (1), which will give the expression for Simpson's second rule, viz.—

$$\tfrac{3}{8}h(y_1 + 3y_2 + 3y_3 + y_4) = \text{area}$$

It is evident $y_1 = a_0$. Now substitute this value in the other equation, and arrange as follows:—

$$a_1h + a_2h^2 + a_3h^3 = y_2 - y_1$$
$$2a_1h + 4a_2h^2 + 8a_3h^3 = y_3 - y_1$$
$$3a_1h + 9a_2h^2 + 27a_3h^3 = y_4 - y_1$$

TCHEBYCHEFF'S RULES.

Tchebycheff's rules for finding areas, displacement, etc., are, rapidly advancing in favour with scientific shipyards, both for their accuracy and simplicity.

To find the Area of a Curvilinear Figure with Two Ordinates.—Bisect the base. Take 0·5773 of the half-length, and set off this distance from the middle point on both sides. Erect ordinates at the two points thus obtained. Call them A and B.

Then area of figure is equal to—

$$\frac{A + B}{2} \times \text{length of base}$$

To find the Area of a Curvilinear Figure with Four Ordinates.—Bisect the base. Take 0·1876 of the half-length, and set it off on both sides of the middle point. Take 0·7947 of the half-length, and set it off on both sides of the middle point. We have now got four ordinates. Call them A, B, C, and D.

Then area of figure is equal to—

$$\frac{A + B + C + D}{4} \times \text{length of base}$$

To find the Area of a Curvilinear Figure with Six Ordinates.—Bisect the base. Take 0·2666, 0·4225, and 0·8662 of the half-length, and set these distances off on both sides of the middle point. We have now got six ordinates. Call them A, B, C, D, E, and F.

Then area of figure is equal to—

$$\frac{A + B + C + D + E + F}{6} \times \text{length of base}$$

To find the Area of a Curvilinear Figure with Three Ordinates.—Bisect the base. Take 0·7071 of the half-length, and set it off on both sides of the middle point. Erect ordinates at these two points, and also at the middle of the base. We have now got three ordinates. Call them A, B, and C.

Then area of figure is equal to—

$$\frac{\mathrm{A} + \mathrm{B} + \mathrm{C}}{3} \times \text{length of base}$$

For five ordinates the divisions are: middle of base; 0·3745; and 0·8325.

For seven ordinates: middle of base; 0·3239; 0·5297; and 0·8839.

For nine ordinates: middle of base; 0·1679; 0·5288; 0·6010; and 0·9116.

Proof of Tchebycheff's Rule with Two Ordinates.—Let the curve be a portion of a parabola whose equation referred to the base and axis at middle of base is—

$$y = a_0 + a_1x + a_2x^2 \;.\;.\;.\;.\;.\;.\;. \qquad (1)$$

where a_0, a_1, a_2, are constants.

For n ordinates the curve is taken to the nth degree. Let $2l$ be length of base, and take origin at middle of the length.

$$\text{Then the area required} = \int_{-l}^{+l} y\,dx \;\;.\;.\;. \qquad (2)$$

Substitute value of y in (1), and—

$$\text{area} = \int_{-l}^{+l} (a_0 + a_1x + a_2x^2)\,dx$$

Integrating—

$$\text{area} = \left[a_0x + \tfrac{1}{2}a_1x^2 + \tfrac{1}{3}a_2x^3\right]_{-l}^{+l}$$

Evaluating—

$$\text{area} = 2a_0l + \tfrac{2}{3}a_2l^3 \;.\;.\;.\;.\;.\;.\;.\;.\;. \qquad (3)$$

Now let this area $= c \times$ the sum of the two ordinates

$$= c(y_1 + y_{-1}) \;.\;.\;.\;.\;.\;.\;.\;. \qquad (4)$$

From equation (1) the value of y_1 is $a_0 + a_1x_1 + a_2x_1^2$

„ y_{-1} is $a_0 + a_1x_{-1} + a_2x_{-1}^2$

Substituting these values of y_1 and y_{-1} in (4)—

$$= c\{(a_0 + a_1x_1 + a_2x_1^2) + (a_0 + a_1x_{-1} + a_2x_{-1}^2)\}$$
$$= c(2a_0 + 2a_1(x_1 + x_{-1}) + 2a_2(x_1^2 + x_{-1}^2 \;.\;.\;. \qquad (5)$$

Since the ordinates are equidistant from the origin—

$$x_1 = -x_{-1} \text{ and } x_1^2 = x_1^2$$
$$\therefore (5) = 2c\{a_0 + a_2(x_1)^2\} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Equating coefficients of a_0 and a_2 in (3) and (6)—

$$2l(a_0 + \tfrac{1}{3}a_2l^2) = 2c\{a_0 + a_2(x_1)^2\}$$
$$\therefore l = c$$
$$(x_1)^2 = \tfrac{1}{3}l^2$$
$$\therefore x_1 = \sqrt{\tfrac{1}{3}}\,.\,l$$
$$\therefore x_1 = 0\cdot5773l$$

Questions on Chapter II.

Ques. A ship has the following weights placed on board: 20 tons 100 feet before ꝏ, 45 tons 80 feet before ꝏ, 15 tons 40 feet before ꝏ, 60 tons 50 feet abaft ꝏ, 40 tons 80 feet abaft ꝏ, 30 tons 110 feet abaft ꝏ. Show how these weights will have the same effect on the trim of the ship as a single weight of 210 tons placed $15\frac{5}{7}$ feet abaft ꝏ (midships).

Weight.	Distance from midships.	Moments.	Direction.
20 tons	100 feet	= 2000 foot-tons	Forward
45 "	80 "	= 3600 "	"
15 "	40 "	= 600 "	"
	Total moment forward	= 6200 "	"
40 tons	80 feet	= 3200 foot-tons	Aft
60 "	50 "	= 3000 "	"
30 "	110 "	= 3300 "	"
	Total moment aft	= 9500 "	

210 tons × $15\frac{5}{7}$ feet abaft = 3300 foot-tons aft
Excess moment aft 9500 − 6200 = 3300 foot-tons aft

Therefore it is proved that the two cases would have the same effect on the trim of the ship.

Ques. A beam 18 feet long has the following weights placed along it, viz. 40 cwts., 90 cwts., 5 cwts., 60 cwts., 140 cwts., and 15 cwts. at the following distances from one end of the beam: 3, 5, 8, $12\frac{1}{2}$, 14, 18 feet respectively. Find where a single support would have to be placed under the beam so that it would be in equilibrium.

Ans. Find C.G. of beams and weights from one end.

Weight.	Distance.	Moment.
40	3	120 foot-cwts.
90	5	450 „
5	8	40 „
60	$12\frac{1}{2}$	750 „
140	14	1960 „
15	18	270 „
350		3590 foot-cwts. = bending moment in foot-cwts.

$\frac{3590}{350} = 10\frac{9}{35}$ C.G. from end taken

Proof that beam would be in equilibrium—

Left.			Right.		
Weight.	Distance.	Moment.	Weight.	Distance.	Moment.
5	$2\frac{9}{35}$	$11\frac{2}{7}$	60	$2\frac{17}{70}$	$134\frac{4}{7}$
90	$5\frac{9}{35}$	$473\frac{1}{7}$	140	$3\frac{52}{70}$	524
40	$7\frac{9}{35}$	$290\frac{2}{7}$	15	$7\frac{52}{70}$	$116\frac{1}{7}$
		$774\frac{5}{7}$			$774\frac{5}{7}$

Ques. Calculate area of a water-plane by (*a*) Trapezoidal; (*b*) Simpson's First and (*c*) Simpson's Second Rules.

Ordinates are 9 feet apart. Half-breadths of plane at ordinates are 0·1, 2·6, 5·0, 8·3, 10·0, 10·8, 11·0, 11·0, 10·5, 9·6, 7·6, 5·5, and 4·0.

TRAPEZOIDAL.

No.	Length.	Multiplier.	Function.
1	0·1	½	0·05
2	2·6	1	2·6
3	5·0	1	5·0
4	8·3	1	8·3
5	10·0	1	10·0
6	10·8	1	10·8
7	11·0	1	11·0
8	11·0	1	11·0
9	10·5	1	10·5
10	9·6	1	9·6
11	7·6	1	7·6
12	5·5	1	5·5
13	4·0	½	2·0
			93·95

93·95 × 9 = 845·55
2

1691·10 square feet. *Ans.* (*a*).

Simpson's First Rule.				Simpson's Second Rule.			
No.	**Length.**	**S.M.**	**Functions.**	**No.**	**Length.**	**S.M.**	**Functions.**
1	0·1	1	0·1	1	0·1	1	0·1
2	2·6	4	10·4	2	2·6	3	7·8
3	5·0	2	10·0	3	5·0	3	15·0
4	8·3	4	33·2	4	8·3	2	16·6
5	10·0	2	20·0	5	10·0	3	30·0
6	10·8	4	43·2	6	10·8	3	32·4
7	11·0	2	22·0	7	11·0	2	22·0
8	11·0	4	44·0	8	11·0	3	33·0
9	10·5	2	21·0	9	10·5	3	31·5
10	9·6	4	38·4	10	9·6	2	19·2
11	7·6	2	15·2	11	7·6	3	22·8
12	5·5	4	22·0	12	5·5	3	16·5
13	4·0	1	4·0	13	4·0	1	4·0
			283·5				250·9

$$\begin{array}{r} \frac{1}{3} \times \frac{9}{1} = 3 \\ 283{\cdot}5 \times 3 = 850{\cdot}5 \\ 2 \\ \hline 1701{\cdot}0 \end{array} \text{ square feet.} \quad \textit{Ans. (b).}$$

$$\frac{3}{8} \times 9 = 3{\cdot}375$$

$$250{\cdot}9 \times 3{\cdot}375 = 1693{\cdot}57 \text{ square feet.} \quad \textit{Ans. (c).}$$

Ques. Write down the rule for finding the transverse position of the C.G. of a half water-plane. The ordinates of the half water-plane are in feet 1·5, 4·3, 8·2, 12·1, 14·0, 12·0, 8·5, 5·2, and 1·2, C.I. = 12′ – 0. Find area and transverse position of the C.G. of the half water-plane.

Ans. Centre of gravity is the centre of weight in a body, or that point at which the weight may be supposed to act, the centre of equipoise or balancing-point.

Rule.—Treat the ordinates by putting them through Simpson's Rule. The result will give the functions of ordinates. Add these together and we get the sum of functions (E^1). Multiply the function of each ordinate by half the length of the ordinate. Add moment of Functions and we get E^2.

$$\text{C.G.} = \frac{E^2}{E^1} \text{ from centre line}$$

BY FIRST METHOD (see p. 26).

No.	Ordinates.	Simpson's multipliers.	Functions of ordinates.	Multiplier.	Function $\frac{\text{ordinate}}{2}$ = moments of F.
1	1·5	1	1·5	0·75	1·125
2	4·3	4	17·2	2·15	36·98
3	8·2	2	16·4	4·1	67·24
4	12·1	4	48·4	6·05	292·82
5	14·0	2	28·0	7·0	196·00
6	12·0	4	48·0	6·0	288·00
7	8·5	2	17·0	4·25	72·25
8	5·2	4	20·8	2·6	54·08
9	1·2	1	1·2	0·6	0·72
			198·5 E^1		1009·215 E^2

$$\text{Transverse C.G.} = \frac{1009{\cdot}215}{198{\cdot}5} = 5{\cdot}08 \text{ feet from centre}$$

$$\text{Area of half water-plane} = 198{\cdot}5 \times \tfrac{1}{3} \times \tfrac{12}{1} = 794$$

$$\text{Area of whole water-plane} = 794 \times 2 = 1588$$

Ans. 5·08 feet from centre = C.G. 794 feet = area

Ques. Find the area and traverse position of the centre of gravity of "half" a water-line plane, the half-breadths in feet being 0·5, 6, 12, 16, 12, 10, and 0·5 respectively; common interval being 15 feet.

Ans. BY SECOND METHOD (see p. 26).

Ordinates.	Half-breadths.	S.M.	Functions.	Squares of ordinates.	S.M.	Products.
1	0·5	1	0·5	0·25	1	·25
2	6·0	4	24·0	36·00	4	144·00
3	12·0	2	24·0	144·00	2	288·00
4	16·0	4	64·0	256·00	4	1024·00
5	12·0	2	24·0	144·00	2	288·00
6	10·0	4	40·0	100·00	4	400·00
7	0·5	1	0·5	0·25	1	0·25
			177·0			2144·50

$$\frac{177 \times 15}{3} = 885 \text{ square feet} \qquad \frac{2144{\cdot}50}{2} = 1072{\cdot}25$$

$$\frac{1072{\cdot}25}{177} = 6{\cdot}05 \text{ C.G. transverse}$$

CHAPTER III.

ON VOLUME, DISPLACEMENT, TONS PER INCH IMMERSION OR EMERSION, CENTRE OF BUOYANCY.

WHEN a body has length, breadth, and thickness, the product of these three measurements, assuming the figure to be regular, as in a cube, is its volume. Volume implies bulk. The measure of the bulk, or volume, of that portion of the floating ship which is under water is its displacement. This displacement may be expressed in tons or cubic feet. It is generally expressed in tons, and when expressed in feet is qualified by calling it the volume of displacement. Water has a certain definite weight; 35 cubic feet of salt water, for example, weigh one ton. So that every 35 cubic feet of a ship's under-water body has displaced or put out of place one ton of water.

We arrive now at one of the fundamental principles governing the science of Naval Architecture. **Every floating body will displace its own weight of water.** If the under-water bulk of a floating vessel be measured by some means, the total weight of the ship and all it contains can be at once determined. This fact may be proved by a very simple experiment. Fill any vessel, such as a bowl, with water to the brim, and then carefully set in it any body that will float. Now weigh the water which has overflown, and it will be found to be exactly the same weight as the body which was set in the vessel.

Archimedes, a famous Greek geometer, first discovered this law, and his principle may be stated as follows: The volume of a body having been found, if the weight of the body is exactly equal to the weight of an equal volume of water, the body will float in the water completely immersed, and with its top edge just level with the surface of the water. If the weight of the body is greater than the weight of an equal volume of water the body will sink, and if the weight of the body is less than the weight of an equal volume of water the body will float.

From this law can be deduced the following laws:—

1. If a vessel is floating at a certain draught, and certain weights be placed on board, the vessel will sink deep enough to displace an additional volume of water, equal in weight to the weights placed on board.

2. If a vessel is floating at, say, 9 feet draught, and certain weights put on board have sunk it to, say, 12 feet draught, the weight of the volume of water displaced between the 9 and 12 feet draughts is equal to the weights which have been placed on board.

The calculation of displacement, then, it will be readily seen, is one of the most important calculations in Naval Architecture, and is also one of the simplest. It is only the application to volumes of the rules already given for areas. The modes of procedure would be as follows:—

Divide the ship longitudinally into any convenient number of equidistant stations or ordinates. Find the area of each of these sections. Put these areas through any of the rules already given for plane figures, and the answer will be the volume in cubic feet.

Example.—A vessel 300 feet long is floating at 10 feet draught. The areas of equidistant sections up to the 10-foot water-line are as follows: 0, 40, 100, 200, 280, 320, 260, 210, 170, 120, 60, 20, 0 square feet respectively. Find the displacement of the vessel in salt water.

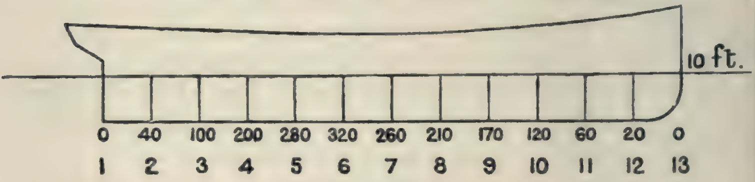


Fig. 28

The vessel has been divided into twelve equal spaces. The common interval, then, will be 300 divided by 12 = 25 feet. The rule to be employed is Simpson's first rule. The work is arranged in tabular form as follows:—

No. of ordinates.	Areas.	Simpson's multipliers.	Products.
1	0	1	0
2	40	4	160
3	100	2	200
4	200	4	800
5	280	2	560
6	320	4	1280
7	260	2	520
8	210	4	840
9	170	2	340
10	120	4	480
11	60	2	120
12	20	4	80
13	0	1	0
			5380
			8⅓
Common interval 25			1793·3
⅓ „ „ 8⅓			43040·0
			44833·3 cubic feet

$\frac{44833{\cdot}3}{35}$ = displacement in salt water
= 1281 tons nearly. *Ans.*

Instead of using the areas of sections, the areas of water-planes might be used.

Example.—A vessel 400 feet long has water-lines 2 feet apart, the areas of which, beginning from the keel, are as follows: 0, 3800, 7800, 10,000, 12,000, 14,000, 15,000 square feet respectively. Find the displacement in salt water up to the 12-feet water-line. As the water-lines are 2 feet apart, the 12-feet water-line is the last given.

No. of water-plane.	Area.	S.M.	Multiples of areas.
Keel	0	1	0
2 feet	3,800	4	15,200
4 „	7,800	2	15,600
6 „	10,000	4	40.000
8 „	12,000	2	24,000
10 „	14,000	4	56,000
12 „	15,000	1	15,000
			165,800
			2
⅓ common interval = ⅔ foot			3)331,600
			110,530 cubic feet

To find the displacement in tons, divide the number of cubic feet by 35.

$$\text{Then displacement} = \frac{110533}{35}$$
$$= 3158 \text{ tons. } \textit{Ans.}$$

It is possible to determine in one table from body plan offsets the displacement without first finding the areas of sections or the areas of water-planes. Assume that the body plan has thirteen equidistant sections drawn on it, representing the vessel divided equally into twelve spaces. Required to find the displacement up to, say, 16-feet water-plane. On the body plan draw water-lines 2 feet apart up to the 16-feet water-line. Prepare a displacement table as follows:—

WATER-LINES.

Ordinates.	S.M.	Keel.		2 feet.		4 feet.		6 feet.		8 feet.		10 feet.		12 feet.		14 feet.		16 feet.	
1	1	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3
2	4	0·4	1·6	0·8	3·2	1·4	5·6	2·8	11·2	4·3	17·2	5·8	23·2	7·3	29·2	8·4	33·6	0·9	36·0
3	2	0·4	0·8	3·5	7·0	5·5	11·0	8·1	16·2	9·7	19·4	10·6	21·2	11·2	22·4	12·0	24·0	12·1	24·2
4	4	0·4	1·6	6·6	26·4	7·5	30·0	10·0	40·0	11·2	44·8	11·8	47·2	12·0	48·0	12·2	48·8	12·3	49·2
5	2	0·4	0·8	8·3	16·6	9·8	19·6	11·7	23·4	12·4	24·8	12·7	25·4	12·7	25·4	12·7	25·4	12·7	25·4
6	4	0·4	1·6	9·1	36·4	10·4	41·6	12·2	48·8	12·8	51·2	13·0	52·0	13·0	52·0	13·0	52·0	13·0	52·0
7	2	0·4	0·8	9·7	19·4	11·5	23·0	12·7	25·4	13·0	26·0	13·0	26·0	13·0	26·0	13·0	26·0	13·0	26·0
8	4	0·4	1·6	9·0	36·0	10·3	41·2	11·1	44·4	12·1	48·4	12·5	50·0	12·8	51·2	12·8	51·2	12·8	51·2
9	2	0·4	0·8	7·2	14·4	8·4	16·8	9·2	18·4	10·1	20·2	11·0	22·0	11·8	23·6	12·0	24·0	12·0	24·0
10	4	0·4	1·6	4·1	16·4	5·9	23·6	8·8	35·2	9·1	36·4	9·9	39·6	10·3	41·2	10·8	43·2	11·2	44·8
11	2	0·4	0·8	1·5	3·0	2·8	5·6	4·4	8·8	5·9	11·8	7·6	15·2	8·6	17·2	9·1	18·2	9·4	18·8
12	4	0·4	1·6	0·6	2·4	1·3	5·2	2·4	9·6	4·1	16·4	5·5	22·0	7·0	28·0	8·1	32·4	9·0	36·0
13	1	0·0	0·0	0·0	0·0	0·0	0·0	0·1	0·1	0·1	0·1	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2
Functions . . .			13·9		181·5		223·5		281·8		317·0		344·3		364·7		379·3		388·1
S.M.			1		4		2		4		2		4		2		4		1
Multiples . .			13·9		726·0		447·0		1127·2		634·0		1377·2		729·4		1517·2		388·1

Multiples.
388·1
1517·2
729·4
1377·2
634·0
1127·2
447·0
726·0
13·9

Sum of multiples = 6960·0

Water-lines apart or common interval of—

$$\text{Water-lines} = 2 \text{ feet}$$

$$\tfrac{1}{3} \text{ of common interval} = \tfrac{2}{3} \text{ feet}$$

$$\left.\begin{array}{l}\text{ordinates or sections apart, or common}\\ \quad\text{interval of ordinates}\end{array}\right\} = \frac{\text{length of vessel}}{12}$$

$$\text{assume length of vessel} = 150 \text{ feet}$$

$$\text{then common interval} = \tfrac{150}{12} = 12{\cdot}5 \text{ feet}$$

$$\tfrac{1}{3} \text{ of common interval} = 4{\cdot}17 \text{ feet}$$

$$\text{sum of multiples} = 6960 \text{ (see displct. table)}$$

$$\text{displacement} = \frac{6960 \times \frac{2}{3} \times 4{\cdot}17 \times 2 \text{ for both sides}}{35 \text{ (to get displct. in tons)}}$$

$$= 1105 \text{ tons. } \textit{Ans.}$$

Explanation.—The first column of the table contains the ordinates or sections arranged consecutively, from aft to forward, or *vice versâ*. The second column contains Simpson's multipliers for the sections. The succeeding columns contain the water-lines as subdivided. Each of these columns for water-lines has been divided into two. In the first of each is written the half-breadth of the section at that water-line as scaled from the body plan. This half-breadth multiplied by S.M. is written in the second column of each water-line.

Note that if any of these second columns was added up and multiplied by one-third the common interval of the section, the result would be the half-area of the water-plane in square feet. Instead, however, of multiplying by this just now, it is deferred until the last; but the sum of these second columns is treated as though it were the area of the water-plane. Put these sums, which are called the function of water-planes, through Simpson's rules, and the multiples of water-planes are found. Add up these multiples, and compare now with the table immediately preceding the displacement table. In that table the sum of the multiples of areas was multiplied by one-third of the common interval of water-planes, and divided by 35 to get the displacement. The same method is followed here, but the multiples of the sections must also be multiplied by one-third the common interval of the sections. As the ordinates written down are only half-breadths of sections, the answer must be multiplied by 2 for both sides.

There are a great many methods of working out displacements. Almost every firm of shipbuilders has a method of its own, but the principle of all is the same. Simpson's first or second rule may be employed, and half-sections and water-lines introduced. The displacement may also be found up to different water-lines, such as 4 feet, 8 feet, 12 feet, 16 feet. The multiples for the functions here would be 1, 4, 1; 1, 4, 1; 1, 4, 1; 1, 4, 1.

The Planimeter.—A quick and accurate method of determining displacement is by means of the planimeter, an instrument invented by Dr. Amsler, which consists of two legs, having at their junction a small wheel which causes a dial face to revolve. A pointer at one extremity is traced over each section of the body plan, and the reading of the dial face records the area of the section, or a figure which, multiplied by the planimeter constant (ordinarily "the square of the scale," as it is termed, *i.e.* if the scale of the body plan is $\frac{1}{4}$ in. = 1 foot, the multiplier would be 4^2 or 16), gives the area. These areas put through Simpson's rules, and multiplied again by one-third the common interval and by 2 for both sides, and divided by 35 to get tons, will give the displacement of the vessel.

Effect on Draught of a Compartment Bilged.—Take a rectangle of cube section.

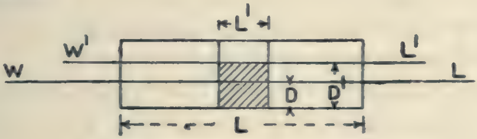


FIG. 29.

The weight of the body itself is not altered, therefore the displacement remains the same. Therefore the two compartments free of water must displace as much as the three did before. Let D be old draught, and D' new draught.

The new draught D' multiplied by the sum of the two free water-lines, which is the total water-line L minus the pierced part L_1, must be equal to the old draught D multiplied by the total water-line.

$$\textit{i.e.}\ D' \times L - L_1 = D \times L$$

$$\therefore D' = \frac{D \times L}{L - L_1}$$

Tons per Inch Immersion.—It is advisable sometimes to know what new draught of water the vessel will float at on the addition of a small weight. If the draught is increased by, say, 1 inch, the added displacement will be found for all practical purposes to be the area of a water-plane at which the vessel is floating multiplied by the added draught, which is in this case 1 inch. It may be stated thus—

$$\text{Added displacement} = \frac{\text{area of water-plane} \times 1 \text{ inch}}{35}$$
$$= \frac{\text{area of water-plane} \times \frac{1}{12} \text{ foot}}{35}$$
$$= \frac{1}{12} \times \frac{1}{35} \text{ of area of water-plane}$$

This added displacement is equal to the number of tons required to sink the vessel 1 inch.

$$\text{Tons per inch therefore} = \frac{1}{12} \times \frac{1}{35} \text{ of area of water-plane}$$
$$= \frac{1}{420} \text{ area of water-plane}$$

This is, of course, for salt water.

Where the vessel is in fresh water, instead of $\frac{1}{35}$ use $\frac{1}{35\cdot9}$, as there are 35·9 cubic feet of fresh water to the ton.

Tons per Inch Emersion is the number of tons required to be taken out of a vessel to lighten it 1 inch, and is obtained in the same way as "tons per inch immersion."

Passage from sea to river water.

Example.—A vessel drawing 20 feet in salt water has a "tons per inch" in fresh water of 50 tons. What will be the draught in river water, assuming the displacement in salt water to be 10,000 tons?

In the example the *weight* of the vessel remains unchanged, but as fresh water is lighter than salt water, the vessel will *sink deeper*, entering the river.

$$\left.\begin{array}{r}\text{Volume of displacement}\\ \text{in salt water}\end{array}\right\} = 10{,}000 \times 35 = 35{,}000 \text{ cubic feet}$$
$$\text{in fresh water} = 10{,}000 \times 35\cdot9 = 35{,}900 \text{ cubic feet}$$
$$\text{difference in volume} = 900 \text{ cubic feet}$$
$$\text{tons per inch in fresh water} = 50 \text{ tons}$$
$$\text{volume of above} = 50 \times 35\cdot9 = 1795 \text{ cubic feet}$$

That is, for every 1795 cubic feet more volume required, vessel sinks 1 inch.

$$\text{Therefore total additional sinkage} = 900 \div 1795 = 0\cdot5 \text{ inch}$$

Example.—A vessel floats at a certain draught in river water. When floating in sea water it was found that an addition of 100 tons was required to bring her to the same draught as in river water. What was the displacement in river water?

Fresh water weighs 63 lbs. per cubic foot
Salt „ „ 64 „ „ „ „

So that salt water is $\frac{1}{63}$ heavier than fresh water.

If the vessel's draught, then, *is to remain constant*, it means that in salt water it will be $\frac{1}{63}$ heaver than in fresh water. The 100 tons was found to be required to keep vessel to same draught.

This 100 tons will be $\frac{1}{63}$ of original displacement.

Therefore original displacement = 100 × 63 = 6300 tons the displacement in salt water will be 6300 + 100 = 6400 tons.

Centre of Buoyancy.—If it were possible to solidify the water, and then to lift the ship out of this medium, leaving a cavity in the solid water or ice, the centre of gravity of this cavity is what is known as the centre of buoyancy. It is important to remember this, that the C.B. is the geometric centre of the cavity left when the vessel is lifted out of the solidified water. The C.B. depends entirely on the form of the vessel. This point will lie along the centre line; it may or may not be exactly mid-length between bow and stern; and its height above keel will vary with the draught. The fore-and-aft position of the C.B. is called the longitudinal C.B. This point is used chiefly for trim calculations. The C.B. above keel is the vertical C.B., and is used chiefly for stability calculations.

Vertical C.B.—For this point the areas of equidistant water-planes are required, and the work is arranged in tabular form as follows:—

Water-plane.	Areas.	S.M.	Products.	Levers.	Moments.
Keel	—	1	—	0′	—
2 feet	—	4	—	2′	—
4 „	—	2	—	4′	—
6 „	—	4	—	6′	—
8 „	—	2	—	8′	—
10 „	—	4	—	10′	—
12 „	—	1	—	12′	—
			P.		M.

$$\frac{M}{P} = \text{C.B. above keel}$$

Another Method.—The vertical C.B. can also be found from the displacement sheet. Looking at displacement table already given, it will be found that the sum of multiples of the water-planes is shown at the foot.

Water-plane.	Functions of water-planes.	S.M.	Multiples.	Levers.	Moments.
Keel	13·9	1	13·9	0′	0·0
2 feet	181·5	4	726·0	2′	1,452·0
4 "	223·5	2	447·0	4′	1,788·0
6 "	281·8	4	1127·2	6′	6,763·2
8 "	317·0	2	634·0	8′	5,072·0
10 "	344·3	4	1377·2	10′	13,772·0
12 "	364·7	2	729·4	12′	8,752·8
14 "	379·3	4	1517·2	14′	21,240·8
16 "	388·1	1	388·1	16′	6,209·6
			6960·0		65,050·4

$$\frac{65050{\cdot}4}{6960{\cdot}0} = 9{\cdot}35 \text{ feet C.B. above keel}$$

This work would all be included with the displacement sheet.

Another Method.—The vertical C.B. may also be found from the displacement curve (see chapter on Curves, etc.).

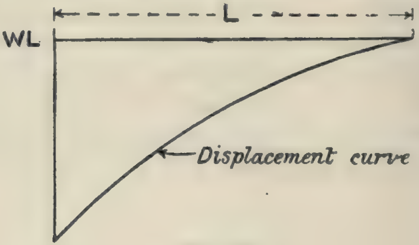


Fig. 30.

Let area of curve = A.

$$\text{Then } \frac{A}{L} = B$$

B = distance of C.B. below water-line.

Divide the distance between the water-line at which the C.B. is required, and the keel into a number of equally spaced draughts to suit S.M. Read off the displacements at each of these draughts.

Put these through S.M. and add the sum of the products. This sum, divided by the greatest displacement, and multiplied by one-third the common interval of the water-lines, will give the vertical C.B. below the highest water-line.

W.L.	Tons.	S.M.	Products.
1	4100	1	4,100
2	3700	4	14,800
3	3200	2	6,400
4	2500	4	10,000
5	1600	2	3,200
6	300	4	1,200
7	0	1	0
			39,700

Assume that No. 1 water-line is 12 feet above No. 7 water-line (the keel). The water-lines are therefore 2 feet apart, and the C.B. below No. 1 water-line will be—

$$\frac{39700 \times 2}{4100 \times 3} = 6{\cdot}45 \text{ feet, or } 5{\cdot}55 \text{ feet above keel}$$

Longitudinal C.B.—To find this point the areas of sections are required, or figures such as the functions which will represent these areas. The C.B. is generally found from either of the end ordinates or about the midship ordinate. Arrange the work as follows:—

Ordinates.	Areas.	S.M.	Products.	Levers.	Moments.
1	—	1	—	0′	—
2	—	4	—	1′	—
3	—	2	—	2′	—
4	—	4	—	3′	—
5	—	2	—	4′	—
6	—	4	—	5′	—
7	—	1	—	6′	—
			P.		M.

$$\frac{M}{P} \times \text{distance of ordinates apart} = \text{C.B. from No. 1}$$

Or the levers might have been arranged about the midship ordinate No. 4 as follows:—

Ordinates.	Areas.	S.M.	Products.	Levers.	Moments.
1	—	1	—	3′	—
2	—	4	—	2′	—
3	—	2	—	1′	—
4	—	4	—	0′	M.
5	—	2	—	1′	—
6	—	4	—	2′	—
7	—	1	—	3′	—
			P.		M^1.

$$\frac{M - M^1}{P} \times \text{distance of ordinates apart} = \text{C.B. from No. 4}$$

This is assuming M to be greater than M^1. The C.B. will, of course, be towards the end that is greatest.

QUESTIONS ON CHAPTER III.

Ques. What is the capacity of a tank in cubic feet of the following dimensions?—

Length = 10·583 feet Breadth = 5·271 feet
Mean depth = 3·968 feet

Ans. $10·583 \times 5·271 \times 3·968 = 221·3469$ cubic feet

Ques. The half-girths of displacement sections of a steel ship are respectively 16, 17·3, 19·2, 21·8, 20·9, 18·1, 16·0 feet. The distance between the sections is 21 feet 8 inches, mean thickness of shell $\frac{8}{20}$ inch. Find displacement of skin.

Sections.	Half-girths.	S.M.	Functions.
1	16·0	1	16·0
2	17·3	4	69·2
3	19·2	2	38·4
4	21·8	4	87·2
5	20·9	2	41·8
6	18·1	4	72·4
7	16·0	1	16·0
			341·0

341·0 = sum of functions
$\frac{1}{3}$ of 21·66 C.I. = 7·22
2462·02
2 = both sides
4924·04 = area in square feet of wetted surface
·05 = $1\frac{1}{2}$ mean thickness of plating in inches
35)246·2020 = cubic feet of skin displacement
Ans. 7·0343 = tons skin displacement

Ques. The areas of the five water-planes of a vessel in square feet, are respectively 4100, 3700, 3200, 2500, 1400, the common interval being 2 feet, and displacement below lowest water-line 50 tons, the centre of buoyancy 9 inches below lowest water-line. Find the displacement and vertical centre of buoyancy.

Areas.	S.M.	Functions.	Levers.	Multiples.
4,100	1	4,100	0	0
3,700	4	14,800	1	14,800
3,200	2	6,400	2	12,800
2,500	4	10,000	3	30,000
1,400	1	1,400	4	5,600
		36,700		63,200

2 ÷ 3 = $\frac{1}{3}$ of C.I. 3)36700
12233·333
2
35)24466·666
Displacement 699·047
below lowest water-line = 50
749·047 tons displacement

63200
2 = C.I.
126400 ÷ 36700 = 3·444 C.B. below A

Displt. tons.		Moment.
699·047	× 3·444 =	2407·52
50	× 8·75 =	437·5
749·047		2845·02

2845·02 ÷ 749·047 = 3·798 = C.B. below A water-line

Ans. Displacement = 749·047 tons
centre of buoyancy = 3·798 feet below A water-line

Ques. A cylindrical pontoon is 50 feet long and 4 feet in diameter. It floats in sea water with its axis at the surface of the water. What is its displacement in cubic feet and tons?

Ans. Displacement in cubic feet $= \frac{4^2 \times 0{\cdot}7854}{2} \times 50 = 314{\cdot}16$

$$\text{Displacement in tons} = \frac{314{\cdot}16}{35} = 8{\cdot}97$$

Ques. A vessel has the "tons per inch" at the several water-planes as follows: 17, 16, 14·6, 12·7, 9·7, 4·5, and 0. Calculate the displacement in tons in salt water. Water-planes are 3 feet apart.

W.P.	T.P.I.	Multiplier.*	Area of W.P.	S.M.	Functions.
1	17·0	420	7140	1	7,140
2	16·0	420	6720	4	26,880
3	14·6	420	6132	2	12,264
4	12·7	420	5334	4	21,336
5	9·7	420	4074	2	8,148
6	4·5	420	1890	4	7,560
7	0·0	420	0	1	—
					83,328

$$\begin{array}{l} 83328 \\ \underline{\quad\ \ 1} = \frac{1}{3}\text{ C.I.} \\ 83328 = \text{volume of displacement} \end{array}$$

Ans. $\frac{83328}{35} = 2380{\cdot}8$ displacement in tons.

* This multiplier could have been used at the end to save work.

Ques. The tons per inch at five equidistant water-planes are respectively 9·8, 8·8, 7·6, 5·9, 3·4. Water-lines are $2\frac{1}{4}$ feet apart.

Below the lowest water-plane is an appendage of 60 tons. Calculate the displacement to load water-line.

T.P.I.	S.M.	Functions.
9·8	1	9·8
8·8	4	35·2
7·6	2	15·2
5·9	4	23·6
3·4	1	3·4
		87·2

$$\frac{87{\cdot}2 \times 2{\cdot}25 \times 420}{3 \times 35} = 784{\cdot}8 \text{ tons.}$$

Appendage = 60 tons.

Ans. 784·8 + 60 = 844·8 tons = displacement to L.W.L.

Ques. The "tons per inch" at the load water-plane of a ship is 30·5.

Find the area of the water-plane in square feet, and the displacement in cubic feet and tons of a layer 4 inches thick in the vicinity of this plane.

Ans. T.P.I. = 30·5

$30{\cdot}5 \times 420 = 12810$ square feet = area of water-plane

$12810 \times \frac{4}{12}$ feet = 4270 cubic feet = displacement of layer in C.F.

$\frac{4270}{35} = 122$ tons = displacement of layer in tons

Ques. A box-shaped vessel 220 feet long × 40 feet broad × 15 feet draught has a W.T. cross bunker amidships 16 feet long filled with coal stowed at 44·8 cubic feet per ton. If the vessel is holed in this bunker, what will be the mean sinkage?

Ans. Without Coal.

$$\text{Lost buoyancy} = 16 \times 40 \times 15 = 9600 \text{ cubic feet}$$

$$\text{mean sinkage} = \frac{\text{lost buoyancy}}{\text{area of intact water-plane}}$$

$$= \frac{9600}{204 \times 40} = \frac{9600}{8160} = 1{\cdot}17 \text{ feet}$$

With Coal.

1 cubic foot of coal, if solid, weighs 80 lbs.

1 „ „ as stowed „ $\frac{2240}{44{\cdot}8} = 50$ lbs.

$\frac{50}{80}$ of space occupied by solid coal.

$\frac{30}{80}$ of space available for water.

$16 \times 40 \times 15 = 9600$ cubic feet lost buoyancy without coal,

with coal, loss of buoyancy = $\frac{30}{80}$ of 9600 = 3600 cubic feet

$$\text{Area of intact water-plane} = (204 \times 40) + (\tfrac{50}{80} \text{ of } 16) \times 40$$

$$= 8160 + 10 \times 40$$

$$= 8160 + 400 = 8560 \text{ sq. ft.} = \text{area of intact W.P.}$$

$$\text{Mean sinkage} = \frac{\text{lost buoyancy in cubic feet}}{\text{area of intact water-plane in square feet}}$$

$$= \frac{3600}{8560} = 0{\cdot}42 \text{ feet mean sinkage}$$

Ques. A ship weighing 10,500 tons floats at a certain water-line in sea water. What is her displacement in cubic feet, and what weight would be required to be removed in order that she may float at the same water-line in fresh water?

Ans. $10{,}500 \times 35 = 367{,}500$ cubic feet

= weight of ship in cubic feet in salt water

$10{,}500 \times 36 = 378{,}000$ cubic feet

= weight of ship in cubic feet in fresh water

∴ 10,500 tons would displace 378,000 cubic feet of fresh water, or 10,500 cubic feet more than of salt water

$\frac{10{\cdot}500}{36} = 291\frac{2}{3}$ tons weight required to be removed

Ques. The water-lines of a vessel are 2 feet apart, and the "tons per inch" at the several water-lines are, beginning with the L.W.L., 14·5, 14·0, 13·4, 12·5, 11·8, 9·9, and 7·0 respectively, displacement below the lowest W.L. is 80 tons, and its C.B. is 12·5 below the L.W.L.

Find the C.B. when floating at load water-line.

No.	T.P.I.	S.M.	Functions.	Levers.	Moments.
1	14·5	1	14·5	0′	—
2	14·0	4	56·0	1′	56·0
3	13·4	2	26·8	2′	53·6
4	12·5	4	50·0	3′	150·0
5	11·8	2	23·6	4′	94·4
6	9·9	4	39·6	5′	198·0
7	7·0	1	7·0	6′	42·0
			217·5		594·0

$$\frac{217\cdot5 \times 420 \times 2}{35 \times 3} = 1740 \text{ displacement in tons}$$

$$\text{C.B.} = \frac{594 \times 2}{217\cdot5} = 5\cdot46 \text{ feet below load water-line}$$

Now, taking account of the appendage—

		C.B.	Moment.
Ship =	1740 tons	5·46	9500
appendage =	80 „	12·5	1000
	1820 „		10500

$$\therefore \text{C.B.} = \tfrac{10500}{1820} = 5\cdot77 \text{ below load water-line}$$

Ques. The water-lines of a vessel are 3 feet apart, and the displacements up to the several water-lines are 2380, 1785, 1235, 740, 325, 60, and 0 tons respectively. Calculate the vertical position of the C.B.

No.	Displacements.	S.M.	Functions.
1	2,380	1	2,380
2	1,785	4	7,140
3	1,235	2	2,470
4	740	4	2,960
5	325	2	650
6	60	4	240
7	0	1	—
			15,840

$$\tfrac{15840}{2380} = 6\cdot65 \text{ feet} = \text{C.B. below load water-line}$$

Note.—This calculation is often used when only the displacement curve of a vessel is available.

Ques. Explain how to calculate displacement and centre of buoyancy by graphic method.

Ans. Find areas of water-lines. Set these up as in Fig. 31, the common interval of which is same as water-line spacing on body plan.

Set off areas of water-lines on each particular plane, and draw in curve of areas of water-lines.

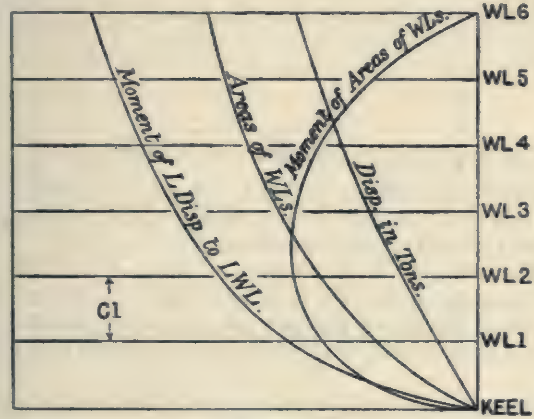


Fig. 31.

By this curve we can get the cubical contents of the displaced water up to any water-line by finding the area of the curve of areas of water-lines graphically.

(The other curves to follow may also be found graphically.)

This will give volume of displacement of the water-planes, which, when divided by 35 or 36, will give displacement of ship in tons in salt or fresh water respectively.

Run the "displacement of ship in tons" curve in.

When this is done, displacement at an intermediate draught can be measured.

The curve for moment of water-line areas is got by multiplying the areas of the water-planes at each water-line by its distance from water-line No. 6. This gives another curve, called "The moment of water-plane areas."

Draw this curve into the various spots on its particular water-line.

For the moment of load displacement to load water-line multiply the displacement in tons at the various water-lines by its distance from the axis or water-line 6, and a series of spots are got which, when set off on the various water-lines, will give curve "moment of load displacement to load water-line."

For the vertical C.B. of a vessel

$$\text{C.B.} = \frac{\text{moment of displacement about L.W.L.}}{\text{volume of displacement below L.W.L.}}$$

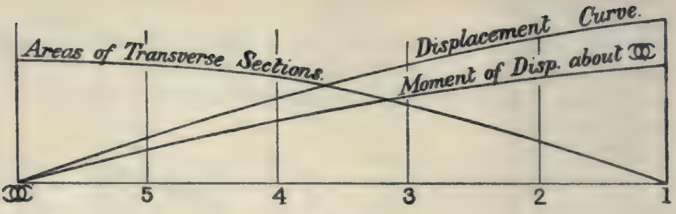


FIG. 32.

To get Displacement and C.B. Longitudinally.

Find areas of the transverse sections by the graphic method.

Set the area of each section on its respective station, and draw in curve termed "curve of areas of transverse sections."

By getting the area of the "curve of areas of tranverse sections" graphically working forward, *i.e.* to 5, to 4, etc., gets volume of displacement to each of the square stations; and by dividing by 35 or 36 gives displacement in salt or fresh water respectively in tons for each section from midships.

To get the moments of displacement about midships multiply the volume of displacement at each of the stations by its distance from the axis or midships. This gives "curve of moment of displacement about midships."

Similar curves can be drawn for the after body. Adding the two displacements together gets total displacement of the ship, and the difference of moments of fore and after body divided by displacement gets the centre of buoyancy forward or aft midship.

Vertical displacement can be measured off vertical scale.

$$\text{C.B.} = \frac{\text{moment of displacement about L.W.L.}}{\text{volume of displacement below L.W.L.}}$$

Displacement longitudinally can be measured off longitudinal scale from midships. The two bodies added will give total displacement.

Longitudinal C.B.

is the difference of moments between fore and after bodies divided by total displacement. This is C.B. forward or aft of midships. If distance from aft perpendicular is required, add or subtract distance of midship ordinate from aft perpendicular.

Ques. Work out a displacement sheet, checking answer by corners.

NOTE.—In the sheet on opposite page, the last two columns are used to find the C.G. of the load water-plane.

Sects.	S.M.	Keel. 1		2-2 W.L. 4		4-4 W.L. 2		6-6 W.L. 4		8-8 W.L. 1		Functions.	S.M.	Second Functions.	L.	Moments.
1	½	0·41 0·41	0·205	0·12 0·48	0·06	0·12 0·24	0·060	0·29 1·16	0·145	2·25 2·25	1·125	4·54	½	2·270	5	11·35
1½	2	0·41 0·41	0·820	0·87 3·48	1·74	1·91 3·82	3·82	3·54 14·16	7·080	6·20 6·20	12·400	28·07	2	56·140	4½	252·63
2	1½	0·41 0·41	0·615	2·16 8·64	3·24	4·06 8·12	6·09	5·87 23·48	8·805	7·66 7·66	11·490	48·31	1½	72·465	4	289·86
3	4	0·41 0·41	1·640	5·48 21·92	21·92	7·27 14·54	29·08	8·37 33·48	33·480	8·95 8·95	35·800	79·30	4	317·200	3	951·60
4	2	0·41 0·41	0·820	7·83 31·32	15·66	8·91 17·82	17·82	9·33 37·32	18·660	9·50 9·50	19·000	96·37	2	192·740	2	385·60
5	4	0·41 0·41	1·640	8·83 35·32	35·32	9·58 19·16	38·32	9·66 38·64	38·640	9·66 9·66	38·640	103·19	4	412·760	1	412·76
6	2	0·41 0·41	0·820	8·83 35·32	17·66	9·58 19·16	19·16	9·66 38·64	19·320	9·66 9·66	19·320	103·19	2	206·280	0	2293·680A
7	4	0·41 0·41	1·640	8·33 33·32	33·32	9·25 18·50	37·00	9·50 38·00	38·000	9·62 9·62	38·480	99·85	4	399·400	1	399·40
8	2	0·41 0·41	0·820	7·04 28·16	14·08	8·29 16·58	16·58	8·82 35·28	17·640	9·14 9·14	18·280	89·57	2	179·140	2	358·28
9	4	0·41 0·41	1·640	4·91 19·64	19·64	6·35 12·70	25·40	7·12 28·48	28·480	7·68 7·68	30·720	68·91	4	275·604	3	826·92
10	1½	0·41 0·41	0·615	2·16 8·64	3·24	3·25 6·50	4·875	4·08 16·32	6·120	4·79 4·79	7·185	36·66	1½	54·990	4	219·96
10½	2	0·41 0·41	0·820	0·95 3·80	1·90	1·62 3·24	3·240	2·24 8·96	4·480	2·74 2·74	5·480	19·15	2	38·300	4½	172·35
11	½	0·00 0·00	0·000	0·00 0·00	0·00	0·00 0·00	0·000	0·00 0·00	0·000	0·00 0·00	0·000	0·00	½	0·000	5	0·00
			12·095		167·78		201·445		220·850		237·92			2207·425		1976·91F
			1		4		2		4		1					

12·095 + 671·120 + 402·890 + 883·400 + 237·920 = 2207·425 ← When these corners agree, the calculation is proved correct.

L. Int. W. Int. Both sides.

$$\frac{2207{\cdot}425 \times 9{\cdot}85 \times 2{\cdot}16 \times 2}{3 \times 3 \times 35} = 298{\cdot}191 \text{ tons displacement to 8–8 load-line}$$

Ques. Vessels in passing from salt to river water in addition to increasing their mean draught frequently change trim. How do you account for this?

Ans. Vessels to possess stable equilibrium and be at rest must have their C.G.s vertically above their C.B.s, so that the upward tendency of the buoyancy is counteracted by the downward tendency of the weight of the ship. When a vessel passes from sea to river water she sinks in the water, and owing to the difference in the displaced volume forward and aft of the C.B., the new position of the C.B. is slightly different longitudinally as well as vertically. Now we have the buoyancy acting upwards through the new C.B., and the weight of the ship concentrated at C.G. acting downwards. These two forces form a couple, and tend to twist the vessel in a longitudinal direction; in other words, to change her trim until the new C.B. is exactly vertically under the C.G. when the vessel comes to rest.

Ques. What is (1) a displacement curve; (2) a tons-per-inch immersion curve? How are they constructed? and what are their uses?

Ans. **A displacement curve** is a curve by means of which you can determine the displacement of a ship at any draught.

To construct this curve set off horizontally a scale of tons displacement, and vertically square it to a scale of mean draughts in feet. Calculate the displacement at the lowest water-plane, and at several other water-planes, generally every 2 feet above lowest water-plane. At each mean draught set off the displacement horizontally, according to the scale provided. Pass a batten through the spots, and if the ship is fair the line given ought to be a fair one.

The use of the displacement curve is as follows: Suppose at any time when the ship is in the water the mean draught is taken. Get the corresponding draught on the scale of draughts, and draw a line parallel to the base line till it meets the curve. Then drop a line at right angles from this spot on to the base, and you can read from the scale what the displacement in tons at that draught would be. Similarly, the mean draught of the ship at any given displacement can be found.

A Tons-per-Inch Curve.—This is a curve by means of which you can determine what weight in tons would have to be put in or taken off the ship to sink or raise her 1 inch parallel to the water-line at any draught.

To construct this Curve.—As in the displacement curve, calculate the tons per inch at a certain number of draughts which extend over all draughts that the ship is likely to float at, the draughts being set off vertically, and the tons per inch horizontally. Pass a batten through the spots obtained, and the resulting line will be a **curve of tons per inch.**

The uses of this curve are as follows: Taking the ship in the water at any mean draught, the effect can be found which the placing of certain weights on board would have on the draught. The area of the water-line at any given draught can also be found by multiplying the tons per inch, obtained from the curve at that draught, by 420. Again, if the displacement curve does not happen to be to hand, you can obtain the displacement at any given draught by dividing from that draught down to the lowest water-line into a number of equally spaced parts to suit one of Simpson's rules, calculating the areas of each water-line at those draughts as mentioned above, and from these obtain the displacement in the usual manner.

CHAPTER IV.

WEIGHTS OF MATERIALS—STOWAGES OF VARIOUS CARGOES.

British oak	54	lbs. per	cubic	foot
Dantzic „	52	„	„	„
Dantzic fir	34	„	„	„
English elm	35	„	„	„
Pitch pine	40	„	„	„
White „	32	„	„	„
Yellow „	27	„	„	„
Baltic red pine	37	„	„	„
American elm	47	„	„	„
Indian teak	46	„	„	„
African „	60	„	„	„
African oak	62	„	„	„
Honduras mahogany	37	„	„	„
Spanish „	54	„	„	„
Californian redwood	25	„	„	„
Greenheart	48	„	„	„
Steel	489	„	„	„
Wrought iron	480	„	„	„
Cast iron	445·3	„	„	„
Fresh water	62·5	„	„	„
Salt water	64	„	„	„

The weights of the various kinds of timber vary so much that a standard weight is almost impossible to be agreed upon. This variation in weights is due chiefly to the amount of moisture in the wood, so that the newer the wood the damper it is, and consequently it is also heavier than well-seasoned timber.

Weights.—A steel plate 1 inch thick weighs 40·8 lbs. per square foot. An iron plate 1 inch thick weighs 40 lbs. per square foot.

Thickness. Inch.	Steel. lbs. per square foot.	Iron. lbs. per square foot.
$\frac{1}{40}$	1·02	1·00
$\frac{1}{20}$	2·04	2·00
$\frac{1}{16}$	2·55	2·50
$\frac{5}{40}$ or $\frac{1}{8}$	5·10	5·00
$\frac{3}{16}$	7·65	7·50
$\frac{5}{20}$ or $\frac{1}{4}$	10·20	10·00
$\frac{3}{8}$	15·30	15·00
$\frac{1}{2}$	20·40	20·00
$\frac{5}{8}$	25·50	25·00
$\frac{3}{4}$ or $\frac{15}{20}$	30·60	30·00
$\frac{7}{8}$	35·70	35·00
1	40·80	40·00

Note that in all the above weights of steel the figure on the decimal side is twice the whole figure. Thus the weight $\frac{5}{20}$ or $\frac{1}{4}$ inch steel is 10 point 20, and so on.

To find weights of angles, assume that the two flanges of the angle have been crushed out flat, and then consider it as a plate. Thus a 3 × 3 × $\frac{6}{20}$ angle would become a $5\frac{14}{20}$-inch plate $\frac{6}{20}$ inch thick. For H bars and channels do the same. This will not be exactly correct, but near enough for all practical purposes.

It is convenient sometimes to have weight in cubic feet per ton.

American elm	50	cubic feet per ton
Yellow pine	70	„ „ „ „
Pitch „	45	„ „ „ „
Teak	40	„ „ „ „
Redwood	68	„ „ „ „
Spruce	70	„ „ „ „
White pine	66	„ „ „ „
Fresh water	35·9	„ „ „ „
Salt „	35	„ „ „ „
Steel	4·58	„ „ „ „
Wrought iron	4·67	„ „ „ „

Specific Gravity.—The specific gravity of a body is the ratio of the weight of any body to the weight of the same volume of fresh water. For example, if a cubic foot of water weighs 62·5 lbs., the specific gravity of another body, a cubic foot of which weighs 34 lbs., will be $\frac{34}{62{\cdot}5} = 0{\cdot}544$.

British oak	0·864	specific	gravity
Dantzic „	0·832	„	„
Dantzic fir	0·544	„	„
English elm	0·56	„	„
Pitch pine	0·64	„	„
White „	0·512	„	„
Yellow „	0·432	„	„
Baltic red pine	0·592	„	„
American elm	0·752	„	„
Indian teak	0·736	„	„
African „	0·96	„	„
African oak	0·992	„	„
Honduras mahogany	0·592	„	„
Spanish „	0·864	„	„
Californian redwood	0·4	„	„
Greenheart	0·768	„	„
Wrought iron	7·68	„	„
Steel	7·82	„	„
Cast iron	7·12	„	„
Fresh water	1·0	„	„
Salt „	1·024	„	„

Stowages of Various Cargoes.—When it is said that a cargo stows at so many feet to the ton, it does not mean that the actual material composing the cargo contains that number of cubic feet to every ton, but it means that the cargo as actually stowed contains that number of cubic feet to the ton. For instance, assuming that the vessel carries oil in casks, it will be readily seen that as the casks are round they cannot stow close together, but a certain amount of space is lost. The stowage of a cargo takes account of this loss, and the figures given are after everything has been allowed for. These figures have been in all cases taken from actual cargoes carried, and will be found to be in strict conformity to the usual practice among shipowners.

Wool	stows	98	cubic feet to the ton	
Cotton	„	112–120	„	„
Hemp	„	100	„	„
Hemp, pressed	„	63·5	„	„
Jute	„	63·5	„	„

A bale of cotton measures about 5′ 4″ × 2′ 9″ × 1′ 9″

A bale of jute weighs 440 lbs.

A bale of jute stows in 52 cubic feet (bottom of beams)

Stalk rice	stows	53	cubic feet to the ton	
Ear rice	„	45	„	„
Bag grain	„	50	„	„
Bulk „	„	45·6	„	„
Bag rice	„	48	„	„
Rice meal	„	65	„	„
Bag oats	„	60	„	„
Bag barley	„	55	„	„
Peas, beans, rye (bags)	„	50	„	„
Linseed	„	56	„	„
Gunny bags, pressed	„	40	„	„

9¼	bags of grain		weigh	1	ton
11	„	barley	„	1	„
12¼	„	oats	„	1	„
9¼	„	peas, beans, rye	„	1	„

Tea	stows	89·6	cubic feet to the ton	
Bags of potatoes	„	70	„	„
Cases of cheese	„	62	„	„
Kegs of butter	„	58	„	„
Cases of butter	„	53	„	„
Hogsheads sugar	„	52	„	„
Refined sugar in bags	„	40	„	„
Ordinary sugar	„	48	„	„
Grape bulk sugar	„	42	„	„
Grape sugar casks	„	60	„	„
Demerara hogsheads	„	40–42	„	„

11 bags of potatoes weigh 1 ton

1 bag of flour weighs 140 lbs.

Bananas nett fruit space	90	cubic feet to the ton	
„ inside insulation	120	„	„
„ top of beams and skin	133	„	„

Frozen mutton	stows	120	cubic feet to the ton	
„ beef	„	90	„	„

1 carcase of frozen mutton	weighs	60 lbs.
1 „ „ beef	„	7 cwts.

The ton in all cases is the British ton of 2240 lbs.

A vessel insulated loses about 18 per cent. of stowage due to insulation, piping, meat battens, etc.

For bottom of beams deduct 4 per cent. beams on every frame, 6 per cent. beams on every alternate frame.

For skin of ship add 4 per cent.

A 14′ dinghy holds . . .	10–12 people
An 18′ „ „ . . .	14–16 „
A 20′ cutter „ . . .	16–20 „
A 22′ „ „ . . .	20–24 „
A 24′ „ „ . . .	24–28 „
A 26′ „ „ . . .	32–38 „
A 28′ „ „ . . .	44–48 „
A 30′ „ „ . . .	50–54 „

	Cubic feet per ton.	Specific gravity.
Refined American petroleum	45·00	0·798
„ Russian „	43·75	0·821
Pennsylvania heavy crude oil	40·52	0·886
Caucasian „ „ „	38·27	0·938
Caucasian light „ „	40·61	0·884
Petroleum refuse	38·69	0·928
Spindle oil	40·11	0·895
Mazoat „	39·46	0·910
Machine oil	39·67	0·905

20 per cent. rise of temperature expands petroleum 1 per cent.

Pure Portland cement as laid in ship	120 lbs.	per cubic foot
„ „ with sand . .	128 „	„
„ „ with coke . .	110 „	„
Black cement as laid in ship . . .	112 „	„
„ „ with coke	100 „	„
„ „ with cork	60 „	„

Questions on Chapter IV.

Ques. The total area of the deck plan of a vessel is 4500 square feet. What would be the surface of deck plank to be worked if there are—

4 hatchways, each 4 × 2½ feet,
2 hatchways, each 10 × 6 feet,

and 2 circular skylights, each 4 feet diameter, over which no plank is to be laid?

Ans. Total area = 4500 square feet.

$$\begin{aligned} \text{Deductions } 4 \times 4 \times 2\tfrac{1}{2} &= 40 \\ 2 \times 10 \times 6 &= 120 \\ 2\,(4^2 \times \cdot 7854) &= 25{\cdot}133 \\ \hline \text{total deductions} &= 185{\cdot}133 \end{aligned}$$

$$4500 - 185{\cdot}133 = 4314{\cdot}87 \text{ square feet of plank}$$

Ques. A transverse iron W.T. bulkhead is worked in a ship at a station whose semi-ordinates are, commencing from below, 6, 9, 10·5, 11·5, 12·5, 12·5, and 12 respectively.

Common interval, 2 feet. Find the weight of the bulkhead from the following particulars: Plates lapjointed, lapbutted, single-riveted. $\frac{3}{8}$ inch thick for lower half-depth, $\frac{5}{16}$ for upper half-depth. Angle bar stiffeners $3\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{16}$ spaced 24 inches apart on one side of the bulkhead.

No.	Half-ordinates.	S.M.	Functions.
1	6·0	1	6·0
2	9·0	4	36·0
3	10·5	2	21·0
4	11·5	4	46·0
5	12·5	2	25·0
6	12·5	4	50·0
7	12·0	1	12·0
			196·0

$$\frac{196{\cdot}0 \times 2 \times 2}{3} = 261{\cdot}32 \text{ square feet, total area of bulkheads}$$

Weight per sq. foot of iron, $\frac{1}{2}$ inch thick = 20 lbs.

weight per sq. foot of iron $\frac{11}{32}$ inch thick = 13·75 lbs.

weight of plating $\frac{11}{32}$ inch mean thickness = 261·32 × 13·75 = 3593 lbs.

Taking plates at 16 inches × 39 inches gives a percentage of about 5·75 % for edges and butts

$$3593 \times 5{\cdot}75\,\% = 206{\cdot}6 \text{ lbs.}$$

weight of plating plus butts and edges = 3799·6 lbs.

running feet of stiffeners = $\frac{261}{2}$ = 131 feet.

weight per foot of bar at $2\frac{1}{2} \times 3\frac{1}{2} \times \frac{5}{16}$ = 5·59 × 131	732·3 lbs.
add 4 % for liners	30
total weight of platings, stiffeners, etc.	4561·9
add 3 % for rivet heads and points.	137·0
Total weight =	4698·9 lbs.

Ans. 2 tons 1 cwt. 3 qrs. 22 lbs.

Ques. The half-ordinates of a portion of a ship's deck not covered by plating are 1·2, 6·0, 9·3, 11·8, 13·4, 14·5, and 15·3 feet respectively. C.I. = 12 feet.

Find weight of beams and planking for this part of the deck, the beams being spaced 4 feet apart and weighing 15 lbs. per foot run, the planking being of pitch pine 4 inches thick. Ignore fastenings.

No.	Ordinates.	S.M.	Functions.
1	1·2	1	1·2
2	6·0	4	24·0
3	9·3	2	18·6
4	11·8	4	47·2
5	13·4	2	26·8
6	14·5	4	58·0
7	15·3	1	15·3
			191·1

4 inches = 0·333 feet

$$\begin{array}{l} 191{\cdot}1 \times \frac{1}{3} \times \frac{12}{1} \\ \quad\ 4 \\ \hline 764{\cdot}4 = \text{area of deck} \end{array}$$

$$\text{Number of running feet of beams} = \frac{764{\cdot}4}{4} = 191{\cdot}1$$

Weight of beams = 191·1 × 15 = 2866·5 lbs.
weight of wood deck = 764·4 × ·333 × 40 lbs. = 10192 lbs.
total weight 2 (2866·5 + 10192) = 26117 lbs.
Ans. 11 tons 13 cwts. 0 qr. 21 lbs.

Ques. The half-ordinates in feet of the deck plan of a ship are respectively 3·0, 16·6, 25·5, 28·6, 29·8, 30·0, 29·8, 29·5, 28·5, 24·2, 0·8. C.I. = 28 feet. If the deck be wholly covered with Dantzic fir 4 inch and 9 inch wide, find the weight of planks and fastenings, the cost of laying and securing planking being 2*s.* 6*d.* per run of 10 feet.

Ordinates.	S.M.	Functions.
3·0	1	3·0
16·6	4	66·4
25·5	2	51·0
28·6	4	114·4
29·8	2	59·6
30·0	4	120·0
29·8	2	59·6
29·5	4	118·0
28·5	2	57·0
24·2	4	96·8
0·8	1	0·8
		746·6

$\frac{1}{3}$ of 28·0 = 9·33 feet

746·6
9·33
6965·778 = area of one side
2
13931·556 square feet area of plane

4 inches = $\frac{1}{3}$ foot

$$\text{weight of deck} = \frac{13931\cdot566}{3} = 4643\cdot855 \times 36 \text{ lbs.}$$

$$4643\cdot855 \times 36 = \frac{167178\cdot78}{112} = 1492 \text{ cwts.}$$

add 5% for fastening = 1492 + 74·6 = 1566·6 cwts.
1566 cwts. = 78 tons 6 cwts.

2*s.* 6*d.* = £$\frac{1}{8}$

$$\text{cost}\,\frac{13931}{9 \text{ inches} \times 10} = \frac{13931}{7\cdot5} = 1857 \times \tfrac{1}{8} = £232\ 2s.\ 6d.$$

$$\left.\begin{array}{r}\text{Weight} = 78 \text{ tons } 6 \text{ cwts.}\\ \text{cost} = £232\ 2s.\ 6d.\end{array}\right\}\ \textit{Ans.}$$

Ques. Calculate the weight of an iron tube 15½ inches diameter inside, 13 feet 4 inches long, and ½ inch thick.

Ans. Since tube is ½ inch thick, outside diameter will equal 16½ inches.

16½ inches = 1·374 feet   15½ inches = 1·291

$1\cdot374^2 \times 0\cdot7854 - 1\cdot291^2 \times 0\cdot7854$ = area of top of tube

1·374	1·291
1·374	1·291
1·887	1·666
0·7854	0·7854
1·48204 = area of 16½-inch circle	1·30847 = area of 15½-inch circle
1·30847	
0·1735 square feet of plating in section	

13 feet 4 inches = 13·33

0·1735
13·33
2·312755 × 480 = weight in lbs.
480
1110·1224 lbs. = weight of tube

Ques. Calculate the weight of the following sketch plate $\frac{5}{8}$ inch thick of steel.

$\frac{5}{8}$ inch = 0·052 feet

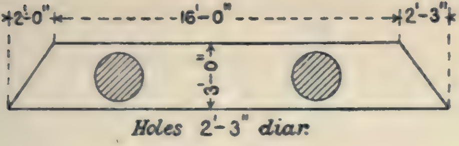


FIG. 33.

18·125 mean length
3 breadth

54·375
7·95 deduction

46·425 square feet
0·052

2·4141
490

1182·909 lbs. *Ans.*

$2{\cdot}25^2 \times 0{\cdot}7854$ = area of circle
2·25

5·062
0·7854

3·975 square feet
2

7·950 area of holes to be deducted

Ques. Calculate weight of $\frac{10}{16}$-inch steel plate of following dimensions.

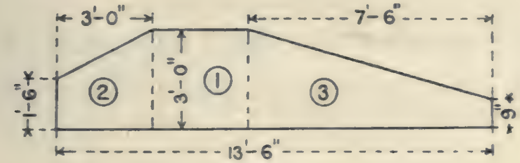


FIG. 34.

Weight of 1 square foot of $\frac{10}{16}$-inch plate = 25 lbs.

No. 1. Part = 3 ft. × 3 ft. × 25 = 225 lbs.

$$,, \ 2. \quad ,, \ = 3 \text{ ft.} \times \frac{1 \text{ ft. } 6 \text{ in.} + 3 \text{ ft.}}{2} \times 25 = 168{\cdot}75 \text{ lbs.}$$

$$,, \ 3. \quad ,, \ = 7{\cdot}5 \text{ ft.} \times \frac{3 \text{ ft.} + 9 \text{ in.}}{2} \times 25 = 350{\cdot}625 \text{ lbs.}$$

225 + 168·75 + 350·625 = 744·3754 lbs.

Ans. 744·3754 lbs.

Ques. Calculate weight of a steel plate 14 ft. 3 in. × 3 ft. 3½ in. × ½ in. with a 13-inch manhole punched out.

Area of plate = 14·25 × 3·29 = 46·8825
area of hole = $1{\cdot}08^2 \times 0{\cdot}7854$ = 0·9161

nett area of plate = 45·9664
20·4 = lbs. per square foot

937·7145 lbs.

112)937·71456(8 cwts. 1 qr. 13 lbs.
896
41·7145
4
166·84
112
54·84
28
43872
10968
1535·52
112
415

Ans. 8 cwts. 1 qr. 13 lbs.

Ques. Find the weight of a wrought-iron pillar 6 feet 10 inches long × $2\frac{1}{4}$ inches diameter.

Ans. Area of section = $0·7854 \times 2\frac{1}{4}\text{ in.}^2 = 3·976$ square inches.

$$\frac{3·976}{144} = 0·0276 \text{ square foot}$$

$$0·0276 \times 6 \text{ feet } 10 \text{ inches} \times 480 = 90·5 \text{ lbs.}$$

Ques. A teak deck plank is 24 feet long and $4\frac{1}{2}$ inches thick. It is 9 inches wide at one end and tapers gradually to 7 inches at the other end. Find its weight.

Ans. Area of one end = 9 in. × $4\frac{1}{2}$ in. = $40\frac{1}{2}$ square inches
area of other end = 7 in. × $4\frac{1}{2}$ in. = $31\frac{1}{2}$ " "

$\frac{72}{2}$ = 36 square inches mean area.

36 square inches = $\frac{1}{4}$ square foot
24 × $\frac{1}{4}$ = 6 cubic feet
6 × 55 lbs. = 2 cwts. 3 qrs. 22 lbs.

Ques. How would you make an estimate of weight and carrying capacity of a steel merchant vessel? and state what extra estimate would have to be made supposing vessel to be a warship.

Ans. Data would be required for a lot of previous vessels, say of the same type and specification, *i.e.* nett or invoiced iron and steel, wood and outfit, machinery and all spare gear. The iron and steel are made up of all iron and steel bars, plates, etc., rivets, pillars, and forgings. The wood and outfit is made up of all joiner, carpenter, and smith work (excluding pillars), winches, awnings, cement and sand, sails, boats, windlass and davits, etc.

Machinery is made up of boilers, funnel, engines, and all spare gear.

Make out probable dimensions of the vessel. Multiplying the three together gets the cubic number, which, when multiplied by a coefficient taken from a similar ship in the data book, will give the invoiced iron and steel.

Add about 4½ per cent. for rivet heads.

These added together give total weight of iron and steel of proposed ship.

Deduct 10 per cent. for scrap, which gives nett weight of iron and steel.

For the engines, look up data book for a ship which has practically the same size of engines and boilers.

Add this weight to that of nett iron and steel.

For wood and outfit a previous ship in data book must be looked up which is similar to one we are considering. Get weight of these added on to our last total, and the sum is equal to light weight of ship.

To this add weight ship is designed to carry (usually allowing a margin). This gives total displacement of vessel.

Extra Estimate to be made for a War Vessel.

The extras would include armour, guns, and mountings, turrets, and any special feature wanted in the ship.

In Government vessels everything is weighed as it goes on board, so that the naval architect has plenty of data to work from.

Ques. The semi-ordinates of the L.W.L. of a vessel are 0·2, 3·6, 7·4, 10·0, 11·0, 10·7, 9·3, 6·5, and 2·0 respectively, and they are 15 feet apart. What weight must be taken out of the vessel to lighten her 3½ inches, and what would be the effect of placing 5 tons on board?

Half-ordinates.	S.M.	Functions.
0·2	1	0·2
3·6	4	14·4
7·4	2	14·8
10·0	4	40·0
11·0	2	22·0
10·7	4	42·8
9·3	2	18·6
6·5	4	26·0
2·0	1	2·0
		180·8

180·8
5 = ⅓ C.I.

904·0 square feet
2

area of plane = 1808 square feet

$$\text{tons per inch immersion} = \frac{1808}{420}$$

$$\therefore \left.\begin{array}{l}\text{amount necessary to be taken}\\ \text{out to raise vessel } 3\tfrac{1}{2} \text{ inches}\end{array}\right\} = \frac{1808}{420} \times 3\tfrac{1}{2}$$

$$= \frac{226}{15} = 15{\cdot}06 \text{ tons}$$

$\frac{1808}{420}$ tons placed on board would sink vessel 1 inch

∴ 5 tons placed on board would sink vessel 1·16 inch

CHAPTER V.

STATICAL STABILITY—THE METACENTRE—MOMENT OF INERTIA—STABILITY CURVES.

THE stability of a ship is not some definite property which she herself possesses apart from what she carries. Stability as applied to a ship means the stability of the stowed ship, of the ship and all she carries. Stability, it will now be seen, is a variable quality, changing with every different cargo, and changing also in the course of the voyage. It is wrong to say that the ship was unstable. The ship may have very little to do with it and the cargo everything. Therefore it is the stowage which should be blamed for the instability. If a vessel is built for a specific trade and to carry a specific cargo, it is possible to design her to be quite stable under these conditions. But when a vessel is built to dimensions fixed by owners and for general trading purposes, it is very difficult to make the ship stable under all conceivable conditions of lading. The captain, or those in charge of the lading, should have a thorough knowledge of their vessel, and what cargoes she can carry and where they ought to be stowed. If the stowage is regulated properly, almost any ship can be made quite stable.

The *primary principles* of stability are: The whole weight of the ship acts *downwards* by the force of gravity through the centre of gravity; the buoyancy of the ship acts *upwards* through the centre of buoyancy. These two forces are equal and opposite. If the centre of gravity and the centre of buoyancy are in the same vertical straight line, the forces neutralize each other, and the vessel remains stationary. If some outward force tends to displace the verticals through these centres, then motion will ensue until the verticals again coincide. *The stability of a ship* is its tendency to remain in, or its power to return to, a given position of equilibrium. In any problem of stability there are only these two forces to be considered, assuming the vessel to be afloat in still water.

In Fig. 35 some external force has inclined the vessel. As no weights on board have shifted, the centre of gravity remains stationary, but as the C.B. depends entirely on the under-water form of the boat, this point will have moved out towards the inclined side. The directions of the forces through these points are shown by the arrows, and their tendency is to push the ship back to the upright position. This is called a righting couple.

Now assume another section in which G is very high, as Fig. 36.

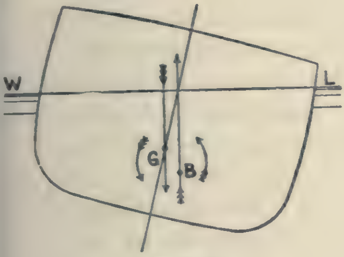


FIG. 35.

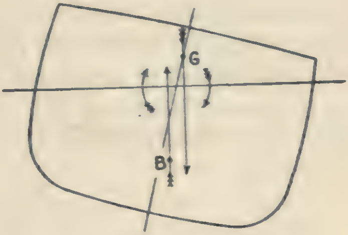


FIG. 36.

The action of the two forces here will tend to incline the vessel still further, and ultimately, it may be, to capsize her. This is called an upsetting couple.

Shortly, if a vessel is inclined to the right, and the vertical through B is to the right of the vertical through G, then the vessel will have a power to right herself. If the vertical through B passes to the left of the vertical through G, then the vessel will tend to incline still further from the upright.

In stability calculations the following particulars have to be determined:—

1. The shift out from the centre line of B, the centre of buoyancy.

2. The length of the arm of the couple, that is, the perpendicular distance between the verticals through G and B.

3. The point where the vertical through B crosses the centre line. This point is called the metacentre.

4. The distance between M, the metacentre, and G, the centre of gravity.

The Metacentre.—The metacentre is the point above which the centre of gravity cannot be raised for stable equilibrium. In other words, the metacentre is "the measure of the centre" (gravity). To find this point, the vertical position of the centre of buoyancy must first be determined, and the distance between this point and the metacentre is found from the equation—

$$\text{B.M.} = \frac{\text{moment of inertia of water-plane}}{\text{volume of displacement}}$$

Inertia is that property which all bodies have of resisting change, either of rest or motion. The moment of inertia is the measure of this resistance. In the moment of inertia (M.I. or I.) of a water-plane the plane must be considered as a very thin layer, perhaps a thousandth part of an inch in thickness, and it is the resistance of this layer to being rocked from side to side as the vessel tends to roll that constitutes its I. The M.I., then, is generally found about an axis, and it is found as follows:—

Imagine the whole area broken up into very small, infinitely small, areas, and each such small area multiplied by the square of its distance from the given axes. If all these products be added together, the resultant will be the M.I. of the total area about the axis.

Consider first the I. of a rectangle as crossed. Take a very small strip, dx, at a distance x from axis (Fig. 37). The sum of all such products as $bdx \times x^2$ will be the M. of the area about the axis XX.

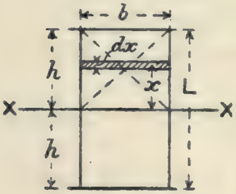


FIG. 37.

Area of elementary strip $= bdx$

M.I. of elementary strip $= bdx \times x^2$

$$\text{M.I. of whole figure} = \int_{x=0}^{x=h} bdx \times x^2$$

$$= \frac{bh^3}{3}$$

but area of whole figure $= bh$

$$\therefore \text{M.I.} = \frac{\text{A}h^2}{3}$$

If we add another rectangle, then—

$$\text{M.I.} = \frac{2bh^3}{3}$$
$$\text{L} = 2h$$
$$\text{L}^3 = (2h)^3$$
$$= 8h^3$$
$$\therefore \text{M.I.} = \frac{2b\text{L}^3}{8 \times 3}$$
$$= \frac{b\text{L}^3}{12}$$
$$\text{but area} = b\text{L}$$
$$\therefore \text{M.I.} = \frac{\text{AL}^2}{12}$$

In considering the M.I. of a plane, suppose the plane to have weight, and this weight to be homogeneous.

1. If the mass of every particle is multiplied by the square of its distance from a straight line, the sum of these products is the M.I. of the plane.

2. If M equal the mass, and K such a quantity that MK^2 is the M.I., then K is called the radius of gyration of the plane about that line.

3. In a curved figure, and bounded by a straight line, such as a half water-plane, cube all the ordinates, and put them through Simpson's rules. One-third of this area is the M.I. for the half water-plane, or two-thirds for the whole water-plane.

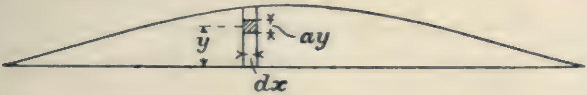


Fig. 38.

$$\text{M.I. of particle } dxay \text{ is } dxay \,.\, y^2 = adxy^3$$
$$\therefore \text{M.I. for whole area} = \tfrac{1}{3}\int dx\, y^3$$
$$\text{and for both sides} = \tfrac{2}{3}\int dx\, y^3$$

i.e. two-thirds the area of a curve of ordinates cubed.

The distance between buoyancy and metacentre was stated to be—

$$= \frac{\text{M.I. of water-plane}}{\text{volume of displacement}}$$

The work is proceeded with in a tabular form as follows:—

Ordinates.	Half-breadths.	Cube of half-breadths.	S.M.	Products.
1	—	—	1	—
2	—	—	4	—
3	—	—	2	—
4	—	—	4	—
5	—	—	2	—
6	—	—	4	—
7	—	—	1	—
				P.

$$P \times \tfrac{1}{3}\,\text{C.I.} = \text{area of curve of ordinates cubed}$$

$$\tfrac{2}{3} \text{ of this area} = \text{M.I. of plane}$$

$$\frac{\text{M.I. of plane}}{\text{volume of displacement}} = \text{B.M.}$$

$$\therefore \text{B.M.} = \frac{P \times \text{C.I.} \times 2}{3 \times 3 \times \text{displacement} \times 35}$$

Note that this B.M. is the distance between the centre of buoyancy in the upright condition and the metacentre. The position of M is correct for inclinations up to, say, seven to ten degrees.

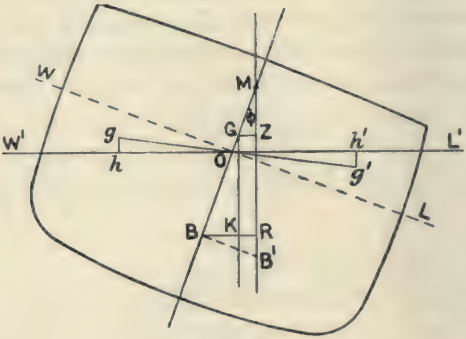


FIG. 39.

Assume that this vessel has been floating upright at water-line WL, and then inclined through angle θ, so that it now floats at water-line W_1L_1. Let B be the centre of buoyancy when upright. The centre of buoyancy will have moved towards the inclined side and downwards. During the inclination a wedge of displacement, WOW_1, has been taken away and put on the other side as L_1OL. Let g and g_1 be the centres of buoyancy of these wedges. B will move along a line parallel to gg_1, and the distance BB_1 will bear the same ration to gg_1 as the volume of the wedge WOW_1 bears to the total displacement.

Let v = volume of the wedge;
V = volume of displacement.

$$v \times gg_1 = V \times BB_1$$

$$\text{or } v \times hh_1 = V \times BR$$

$$\therefore \frac{v \times hh_1}{V} = BR$$

$$BR = BK + KR \therefore KR = BR - BK$$

$$GZ = KR$$

$$BK = BG \sin \theta$$

$$GZ = BR - BG \sin \theta \text{ or}$$

$$GZ = \frac{v \times hh_1}{V} - BG \sin \theta$$

This is Atwood's expression for the righting arm. In the above figure the intersection of the two water-planes has been drawn at the centre line. This may or may not be the case. Generally the intersection of the two planes lies a little towards the inclined side. This will be made clear by the following diagram.

Although this is not an ordinary midship section of a vessel, yet, as the sections towards the two ends have approximately this form, the section may be taken as a mean of all the sections of the ship. The vessel at all inclinations should have the same displacement. It is obvious that the vessel heeled to W_1L_1 will have a greater displacement than when floating at WL, because the immersed wedge LOL_1 is greater than the emerged wedge WOW_1. The new water-line will be, say, XSY, and the intersection with the original water-line will take place a little to the right of O.

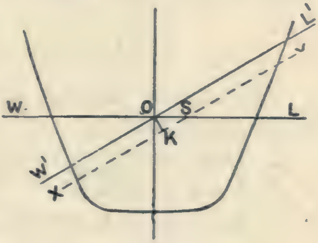


FIG. 40.

The vessel floating at the water-line XSY will be floating at the right displacement. Floating at WOL_1 water-line there is too much displacement by the amount of the layer WL_1XY. This amount is very nearly equal to the area of the water-plane WL_1 multiplied by the thickness of the layer OK. Call this difference a.

$$\text{Then } a = \text{area } WL_1 \times OK$$

Let θ = angle of inclination.

$$\text{Then } \frac{OK}{OS} = \sin\theta$$

$$OK = OS \sin\theta$$

$$\text{dividing by } \sin\theta \therefore \frac{OK}{\sin\theta} = \frac{OS\sin\theta}{\sin\theta} = OS$$

$$a = \text{area } WL_1 \times OK$$

$$\therefore OK = \frac{a}{\text{area of } WL_1}$$

$$\text{dividing by } \sin\theta \therefore \frac{OK}{\sin\theta} = \frac{a}{\text{area of } WL_1 \sin\theta}$$

$$\therefore OS = \frac{a}{\text{area of } WL_1 \sin\theta}$$

That is to say, divide the difference of displacement by the area of the inclined water-plane, multiplied by the sine of the angle of inclination, and the resultant will be the position from the centre line of the point of intersection with the original water-plane of the new water-plane.

CALCULATION OF CROSS CURVES.

Stability is usually calculated for two or three different conditions, such as—

1. Light condition.
2. Load condition.
3. Load condition with coals burned out.

First arrange the angles of inclination, say, 15°, 30°, 50°, 70°, 90°.

Assume that the calculation is first for the load condition. Prepare a complete body plan for the fore body and a complete body plan for the after body. Draw on the load water-line and also the inclined angles.

Find by triangles the area of each section of immersion and emersion at the inclination assumed. Also, spot the C.G. of each section. Draw a line, XX, perpendicular to the inclined water-plane. This is the line about which the moments of the wedges are taken.

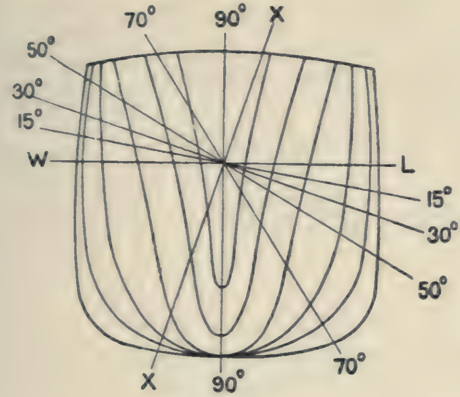


Fig. 41.

Now prepare a table as follows:—

Submerged Wedge.

Ordinates.	Areas.	S.M.	Products.	Levers about XX.	Moments.
1	—	1	—	—	—
2	—	4	—	—	—
3	—	2	—	—	—
4	—	4	—	—	—
5, etc.	—	2, etc.	—	—	—
			S		M.

$$\text{Distance of C.G. of wedge from XX} = \frac{M}{S}$$

Also find the volume of the wedge by multiplying S by $\frac{1}{3}$ C.I. Repeat this calculation for the emerged wedge.

	Volume.	Levers about XX.	Moments.
Submerged wedge	—	—	—
Emerged "	—	—	—
	S_1		M.

S_1 is the difference between the volumes of the submerged and emerged wedges. Now make a correction for this difference. Find the length of the inclined water-plane as follows:—

Ordinates.	Sub-merged.	Emerged.	Total.	S.M.	Products.	Leverage.		Moments.	
						Sub-merged.	Emerged.	Sub-merged.	Emerged.
1	—	—	—	1	—	—	—	—	—
2	—	—	—	4	—	—	—	—	—
3, etc.	—	—	—	2, etc.	—	—	—	—	—
					S			+ S	E
								− E	
								S) —	
								G	

The leverage is half the difference of the two ordinates.

Total moment (M) = —
$S_1 \times G =$ —
Total volume of displacement) nett moment
BR

In $S_1 \times G$ note that if the greater volume is on the emerged side, and the C.G. of it on the emerged side, the moment obtained has to be deducted from the total moment. If the greater volume is on the submerged side, and its C.G. on the submerged side, the moment obtained has to be added to the total moment. The contrary also holds good.

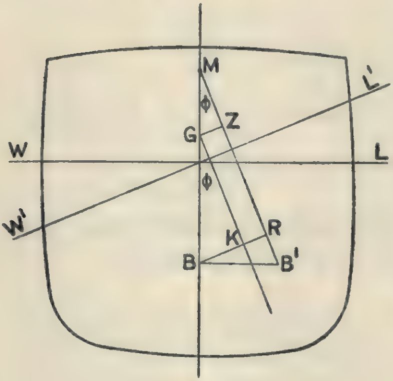


FIG. 42.

$$GZ = BR - BG \sin \theta$$

$$\sin \theta = \frac{BR}{BM}$$

Now proceed to find the BR in the same manner for 30°, 50°, 70°, 90°. Also proceed to find the BR for the other draughts for all the different angles for inclination.

Now construct cross curves of stability.

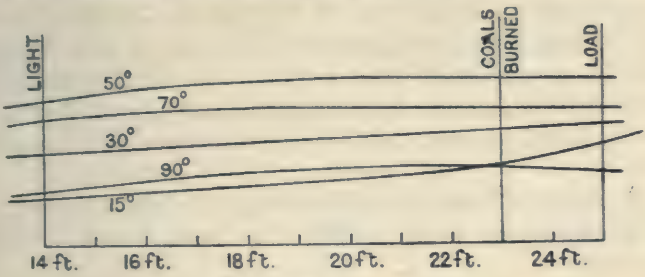


FIG. 43.

Set up at the different draughts the GZ found for the different inclinations. Run lines through each series of spots, and these are the cross curves of stability.

Now construct stability curves.

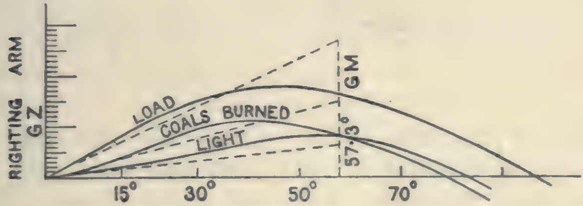


FIG. 44.

At 57·3 set up the GM for each condition. This is the angle at which circular stability is nothing, and this line should be a tangent to the stability curve at 0°.

The cross curves show constant inclination at varying displacements. The stability curves show constant displacement at varying inclinations. The cross curves show the value of the righting arm GZ. A curve of righting moment could also be made showing the foot tons, the value of W (displacement) × GZ. In preparing the body plan the sections are drawn to the uppermost continuous deck, and to the top of the wood, also to the mean thickness of plating. Bulwarks are not usually allowed for. If a water-tight poop, bridge, or forecastle become immersed at the higher angles of inclination, the value of their buoyancy should be calculated.

As these curves have been considered with the vessel stationary, they are called static curves.

For an ordinary ship-shaped vessel the transverse metacentre may remain unchanged up to 10°, but if the form changes rapidly M may not be right for 2°. In a vessel with high freeboard M is practically fixed for 10°. The G.M. should not be less than 10 inches, and have a righting arm of 10 inches at 45°. Low freeboard vessels should have correspondingly increased G.M.

Dr. Amsler's Integrator.—By means of this instrument the GZ is determined much quicker than by the method already described.

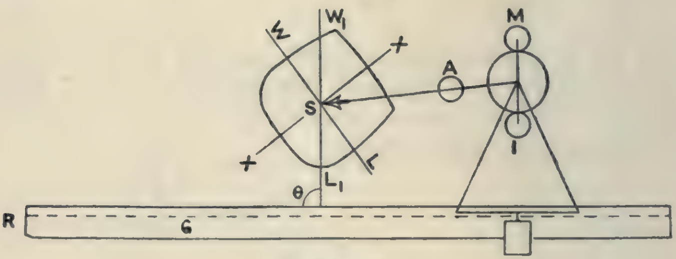


FIG. 45.

The body plan is so set that the inclined water-plane is at right angles to the ruler R. This steel ruler has a groove in it, G, along which the wheels of the instrument travel.

The centre of gravity is always assumed to be at the intersection of the water-planes S.

The readings at A give the areas of the sections, and from the areas the total displacement can be found. The readings at M give the moments. Note that M is always the outside dial. The total moment divided by the total displacement gives the leverage. If the actual C.G. is at S, this leverage will be the GZ. If S is above or below G, then a correction is made. If S is above G, add to the lever SG sin θ. If S is below G, deduct from the lever SG sin θ.

Now set up on the cross curve the value of GZ on the displacement found at the inclined water-plane. Repeat this operation for all drafts and inclinations required.

Along with the instrument is supplied a book, giving multipliers required for areas and moments according to the scale of the drawing. Quite a number of calculations can be performed by means of the integrator, but its great use is for determining the value of GZ for cross curves of stability. The student is referred to the 1884 *Transactions of the Institute of Naval Architects* for a paper by the inventor, giving examples of calculations for which the instrument may be used.

Notes on Stability.—

G.M. for sea-going ship should never be less than 10 inches.
„ of battleship, 3 feet 6 inches.
„ of transatlantic mail steamer, 1 foot.
„ of a cruiser, 2 feet 6 inches.
„ of a large cargo boat, 2 feet.
„ of a paddle steamer, 2 feet.
„ of a cross Channel steamer, 1 foot 6 inches.

An ordinary sea-going ship should have a range of stability of 70°. Stability varies as the square of the breadth and inversely as the draft. A 300-ft. steamer had in the loaded condition a maximum righting lever of 8 in. An exactly similar ship under similar conditions, but 2 feet broader, had a maximum righting lever of 12 in. Freeboard is a most important factor in stability, as the stability immediately begins to decrease rapidly when the deck edge gets under water, so that every additional inch of freeboard increases the vessel's range of stability.

The M.I. increases directly as the length increases, therefore metacentre is independent of the length. Increase of length generally carries itself only.

QUESTIONS ON CHAPTER V.

Ques. The half-ordinates of a ship's L.W.L. are respectively 0·5, 5·0, 9, 10, 12, 12, 11, 10, 6, and 1. C.I. = 11 feet 6 inches.

Find height of transverse metacentre above centre of buoyancy.

Displacement = 410 tons

No.	Half-ordinates.	Cubes of half-ordinates.	S.M.	Functions.
1	0·5	0·175	1	0·125
2	5·0	125·000	3	375·000
3	9·0	729·000	3	2187·000
4	10·0	1000·000	2	2000·000
5	12·0	1728·000	3	5184·000
6	12·0	1728·000	3	5184·000
7	11·0	1331·000	2	2662·000
8	10·0	1000·000	3	3000·000
9	6·0	216·000	3	648·000
10	1·0	1·000	1	1·000
				21241·125

$$\frac{21241{\cdot}125}{1} \times \frac{3}{8} \times \frac{11{\cdot}5}{1} = 91602{\cdot}33$$

2 for both sides

3)183204·66

61068·22 = moment of inertia about centre line

volume of displacement = 410 × 35 = 14350

$$\frac{\text{moment of inertia}}{\text{V.}} = \text{B.M.} \therefore \frac{61068{\cdot}22}{14350} = 4{\cdot}25 = \text{B.M.}$$

4·25 = 4 feet 3 inches. *Ans.*

Ques. State the expressions giving the moment of statical stability (1) for any angle; (2) for an angle within the metacentric limits. A vessel is 300 feet long × 46 feet wide × 18 feet draught, and 4500 tons displacement. Tons per inch 26. C.G. 18 feet above the base. Find the approximate moment of force to keep the vessel inclined 5°.

(1) Moment of statical stability = GZ × displacement
GZ = distance between verticals through C.B. when inclined, and C.G.
(2) Moment of statical stability = G.M. sin θ × displacement
G.M. = height of metacentre above C.G.
sin θ = sine of the angle of inclination
Δ = displacement in tons

Area of W.L. = 26 × 420 = 10920 sq. feet.
area of rect. containing W.L. = 300 × 46 = 13800 sq. feet.

$$\therefore \text{coefficient of W.L.} = \tfrac{10920}{13800} = 0{\cdot}79 = \text{fairly full W.L.}$$

$$\therefore \text{approximate B.M.} = \frac{L \times B^3 \times 0{\cdot}055}{4500 \times 35} = \frac{300 \times 46^3 \times 0{\cdot}055}{4500 \times 35} = 10{\cdot}2 \text{ feet}$$

$$\text{approximate depth of C.B. below L.W.L.} = \tfrac{1}{3}\left(\frac{H + V}{2 + A}\right)$$

H. = load draught;
V. = volume of displacement;
A. = area of L.W.L.

$$\text{C.B. below} = \text{L.W.L.} = \tfrac{1}{3}\left(9 + \frac{4500 \times 35}{10920}\right) = \tfrac{1}{3}(9 + \tfrac{375}{26}) = 7{\cdot}81 \text{ feet.}$$

∴ C.B. = 18 − 7·81 = 10·19 feet above base; that is, 7·81 feet below C.G.

B.M. = 10·2 feet.

∴ G.M. = 10·2 − 7·81 = 2·39 feet

(sine 5°)

Ans. Approximate moment of S.S. = 2·39 × 0·087 × 4500 = 936 foot-tons.

Ques. Show graphically the three states of equilibrium.

Ans. Fig. 46. Stable equilibrium, because M. is above G.

Fig. 47. Unstable equilibrium, because M. is below G.

Fig. 48. Neutral equilibrium, because M. and G. coincide.

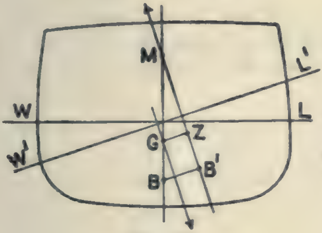


FIG. 46.

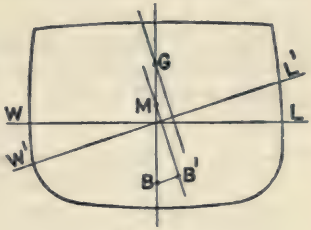


FIG. 47.

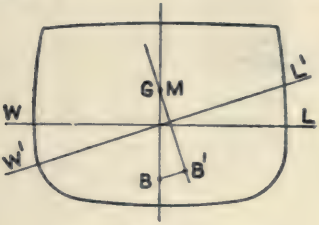


FIG. 48.

Ques. A boxed-shaped vessel 100 feet × 15 feet floats at a draught of of 7 feet. The centre of gravity being at the height of the W.L., find the height of the M.G.

Formula. Moment of inertia ÷ by volume of displacement = M.B.

$$\frac{I}{V} = \text{M.B.}$$

volume of displacement = 100 × 15 × 7 feet = 10500 cubic feet

$$\text{moment of inertia} = \frac{L \times B \times B^2}{12}$$

$$\text{or } \frac{\text{area} \times B^2}{12} = \text{M.I.}$$

$$\text{then } \frac{100 \times 15 \times 225}{12} = \frac{33750}{12} = 28125 \text{ with axis at centre-line of ship}$$

centre of buoyancy = 3·5 feet above base

centre of gravity = 7 feet above base

∴ transverse metacentre above C.B. = $\frac{28125}{10500}$ = 2·678 feet

centre of buoyancy above base = 3·5 feet
transverse metacentre above buoyancy = 2·678 feet

transverse metacentre above base = 6·178 feet
centre of gravity above base = 7·0

negative M.G. = 0·822 foot, or 9⅞ inches negative stability

Ans. Therefore vessel will be in unstable equilibrium by having a negative metacentric height of 0·822 foot, or 9⅞ inches.

Ques. The half-ordinates of a ship's L.W.L. are respectively 0·25, 4, 8, 10, 11, 12, 12, 11, 9, 7, and 0·7 feet. Ordinates 13 feet apart. Find metacentric height. Displacement being 410 tons. Assume B.G. 2 feet 6 inches. What would be the moment of statical stability if the ship was heeled, say, 9° from upright = sine θ° 0·1564?

Half-ordinates.	Cubes of half-ordinates.	S.M.	Functions.
0·25	0·015	1	0·015
4·00	64·000	4	256·000
8·00	512·000	2	1,024·000
10·00	1,000·000	4	4,000·000
11·00	1,331·000	2	2,662·000
12·00	1,728·000	4	6,912·000
12·00	1,728·000	2	3,456·000
11·00	1,331·000	4	5,324·000
9·00	729·000	2	1,458·000
7·00	343·000	4	1,372·000
0·70	0·343	1	0·343
			26,464·358

26464·358 × $\frac{1}{3}$ of $\frac{1}{3}$ of 13 feet (C.I.) × 2 (both sides) = 76452·610

$$\frac{76452{\cdot}610}{14350 \text{ vol. of displct.}} = 5{\cdot}33 \text{ M.B.} - 2{\cdot}5 \text{ B.G.} = 2{\cdot}83 \text{ metacentric height}$$

MG × sine θ = leverage GZ × displacement = initial statical stability up to 9°

2·83 (MG) × 0·1564 (sine θ) = 0·442 (GZ) × 410 tons displct. = 181·406 foot-tons

Ans. 181·406 foot-tons = moment of initial statical stability.

Ques. Find the moment of inertia of a rectangle when the axis is one of the sides.

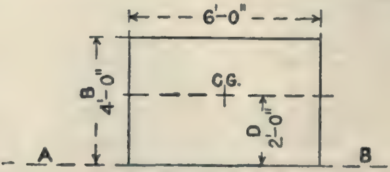


FIG. 49.

Formula—

$$\frac{\text{area} \times B^2}{12} = \text{M.I. about axis passing through C.G.}$$

$$\frac{A \times B^2}{12} + A \times \text{distance}^2 = \text{M.I. about one side}$$

Example—

$$\frac{24 \times 16}{12} + (6 \times 4) \times 2^2 = 128$$

moment of inertia about one side = 128

Another method. *Formula*—

$$\frac{A \times B^2}{3} = \text{M.I. about one side}$$

Example—

$$\frac{24 \times 16}{3} = 128$$

M.I. about one side = 128 as before

Ques. Find the moment of inertia of a rectangle with its axis passing through the C.G. parallel to the base of the figure.

Formula—

$$\frac{L \times B \times B^2}{12} = \frac{L \times B^3}{12} = \text{moment of inertia}$$

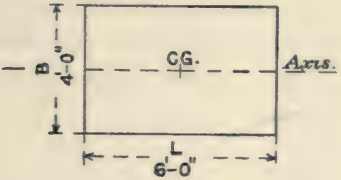


FIG. 50.

Example—

$$\frac{6 \times 4 \times 4^2}{12} = \frac{6 \times 4^3}{12} = \tfrac{384}{12} = 32$$

moment of inertia through given axis = 32

Ques. Find the moment of inertia of an equilateral triangle with its axis passing through the centre of gravity of the figure parallel to the base.

Formula—

$$\frac{L \times B \times B^2}{18} = \frac{L \times B^3}{18} = \text{moment of inertia}$$

Example—

$$\frac{6 \times 4 \times 4^2}{18} = \frac{6 \times 4^3}{18} = \frac{21\frac{1}{3}}{2} = 10\tfrac{2}{3}$$

moment of inertia through given axis = $10\frac{2}{3}$

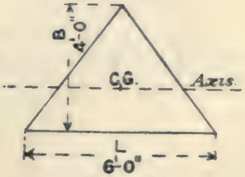


FIG. 51

Ques. Find the moment of inertia of a circle with its axis passing through the centre of gravity.

Formula—

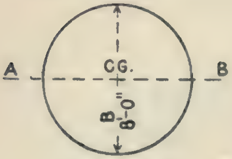


FIG. 52.

$$\frac{\text{area} \times B^2}{16} = \text{moment of inertia}$$

Example—

$$\frac{8 \times 8 \times 0{\cdot}7854 \times 8^2}{16} = \frac{321{\cdot}66}{16} = 201$$

moment of inertia through given axis = 201

Ques. Find the moment of inertia of a rectangle with its axis lying outside its surface at the distance h parallel to ab.

First find the M.I. of the rectangle when the axis passes through the C.G., the formula being

$$\text{M.I.} = \frac{\text{area} \times B^3}{12}$$

then add the area × square of distance, the result will be the M.I. of the rectangle about the axis AB.

Formula—

$$\frac{L \times B^3}{12} + (L \times B \times D^2) = \text{M.I. about AB}$$

Example—

$$\frac{6 \times 4^3}{12} + (6 \times 4 \times 12^2) = \tfrac{384}{12} + 3456 = 3488$$

Moment of inertia about axis AB = 3488

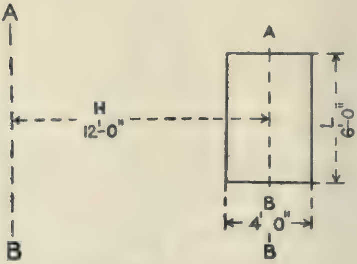


FIG. 53.

Ques. The half-ordinates of the load water-plane of a vessel are respectively 0·8, 1·5, 8·0, 9·0, 8·1, 5·5, 1·2 feet. Find the moment of inertia of the water-plane about the centre line, the ordinates being 12 feet apart.

Half-ordinates.	Cubes of half-ordinates.	S.M.	Functions.
0·8	0·512	1	0·512
1·5	3·375	4	13·500
8·0	512·000	2	1024·000
9·0	729·000	4	2916·000
8·1	531·441	2	1062·882
5·5	166·375	4	665·500
1·2	1·728	1	1·728
			5684·122

Common interval = 8 feet

Moment of inertia $= 5684{\cdot}122 \times \frac{12}{3} \times \frac{2}{3} = 15157{\cdot}658$. *Ans.*

Ques. Explain why a square log of oak usually floats with its sides vertical while a similar log of fir usually floats with its diagonal vertical. At what specific gravities would a log float in both positions?

		Spec. gravity.
Approximate weights	1. English oak, 52 lbs. per cubic foot	$\frac{52}{62{\cdot}5} = 0{\cdot}832$
	2. Fir 36 " "	$\frac{36}{62{\cdot}5} = 0{\cdot}576$

In the case of oak, when the log floats with sides vertical, the centre of gravity is below the metacentre, and therefore the log in that position possesses stable equilibrium, and if inclined from that position would return to it. If it did not float with its sides vertical, then it would float with diagonal vertical, as the C.B. in that position would act vertically through the C.G., which is a condition of equilibrium. However, as will be proved in the example worked, the log would not float in this position as, owing to the smaller water-plane, the metacentre would come below the C.G., and the log when held in that position would be in unstable equilibrium.

The case of the log of fir is the converse of this, for when the log has its side vertical the C.G. is above the metacentre, and when it has its diagonal vertical its C.G. is below the metacentre.

(A) Assume a log of oak 1 foot square in section.

Specific gravity = 0·832.

(1) With the sides vertical.

The area of immersed section = 0·832

$\therefore$ 0·832 foot = draught

Then $B = \frac{0{\cdot}832}{2} = 0{\cdot}416$ foot above the bottom.

Then, as G. is at the centre of the log, $B.G. = 0{\cdot}5 - 0{\cdot}46 = 0{\cdot}084$ foot.

$$B.M. = \frac{L \times 1^3}{12 \times L \times 1 \times 0{\cdot}832} = 0{\cdot}100$$

$$\therefore G.M. = 0{\cdot}016$$

The log is in stable equilibrium as M. is above G.

(2) **With the diagonal vertical.—**

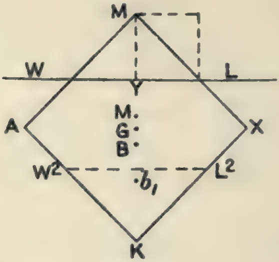


FIG. 55.

$$WAK \times L = 0{\cdot}832 \text{ square foot}$$
$$\text{Area of M.W.L.} = 1 - 0{\cdot}832 = 0{\cdot}168 \text{ square foot}$$
$$MY^2 = 0{\cdot}168$$
$$MY = \sqrt{0{\cdot}168}$$
$$\text{W.L.} = 2\sqrt{0{\cdot}168}$$
$$\text{W.L.} = 0{\cdot}82 \text{ foot}$$
$$\therefore \text{B.M.} = \frac{L \times 0{\cdot}82 \times 0{\cdot}82 \times 0{\cdot}82}{12 \times L \times 0{\cdot}832} = \frac{0{\cdot}0688}{1{\cdot}248}$$
$$= 0{\cdot}054 \text{ foot}$$

C.B. of portion WW_2L_2L is at G (making $A \times W_1L_1$ equal to $WL \times A$)
C.B. of portion W_2L_2K is $\frac{2}{3}$ MY from K—

$$= \tfrac{2}{3} \times \frac{0{\cdot}41}{1} = 0{\cdot}273 \text{ foot} = (\tfrac{1}{2}\sqrt{2} - 0{\cdot}273) \text{ from G}$$
$$= 0{\cdot}757 - 0{\cdot}273 = 0{\cdot}484 \text{ from G}$$

Moment of immersed portion about G—

$$\text{W.L. } W_2L_2 \times 0 = 0$$
$$\frac{0{\cdot}168 \times 0{\cdot}484}{0{\cdot}832} = 0{\cdot}0813$$
$$0{\cdot}0813 = \text{mt.}$$
$$\text{C.B. below G} = \frac{0{\cdot}0813}{0{\cdot}832} = 0{\cdot}097 = \text{B.G.}$$

But B.M. has been found to be only 0·054.

∴ as the C.G. comes above the metacentre the log possesses unstable equilibrium when floating with its diagonal vertical.

(B) Assume a log of fir 1 foot square in section.

Specific gravity = 0·576 foot

(1) **Take the log floating with its sides vertical.**

$$\text{B.G.} = 0{\cdot}5 - \frac{0{\cdot}576}{2} = 0{\cdot}212 \text{ foot}$$
$$\text{B.M.} = \frac{L \times 1^3}{12 \times L \times 0{\cdot}576} = \frac{1}{5{\cdot}412} = 0{\cdot}18 \text{ foot}$$

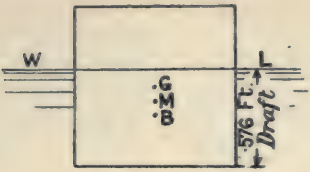


FIG. 56.

∴ as G comes above M the log is in unstable equilibrium.

(2) **Floating with its diagonal vertical.**

Area of WAK × L = 1·0 − 0·576 = 0·424 square foot

$$MY^2 = 0{\cdot}424$$

$$W.L. = 2\sqrt{0{\cdot}424}$$

$$W.L. = 1{\cdot}3 \text{ foot.}$$

$$B.M. = \frac{L \times 1{\cdot}3 \times 1{\cdot}3 \times 1{\cdot}3}{12 \times L \times 0{\cdot}576} = 0{\cdot}28 \text{ foot}$$

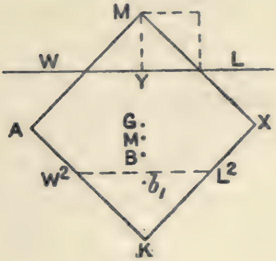


FIG. 57.

C.B. of portion WLL_2W_2 is at G (making A × L_2W_2 equal to WL × A).

$$\therefore \text{C.B. of portion } W_2L_2K = \tfrac{2}{3} \times \frac{0{\cdot}65}{1} \text{ from K}$$

$$\text{,, \quad ,,} \quad = \left(\tfrac{1}{2}\sqrt{2} - \tfrac{2}{3} \times \frac{0{\cdot}65}{1}\right) \text{ from G}$$

$$\text{,, \quad ,,} \quad = 0{\cdot}317 \text{ from G}$$

$$\therefore \text{C.B. of displaced water} = \frac{0{\cdot}424 \times 0{\cdot}317}{0{\cdot}576} = 0{\cdot}23 \text{ foot from G}$$

that is, B.G. = 0·23 foot

But B.M. has been found to be 0·28 foot.

∴ the metacentre comes above the centre of gravity, and when floating in this position the log possesses stable equilibrium.

(C) To find the specific gravities at which a log would float in either position.

When floating upright G. and M. will coincide.

Assume a log 2 feet square.

Then B.G. = B.M.

$$\text{B.G.} = 1 - \tfrac{1}{2}x = \frac{2 - x}{2}$$

$$\text{B.M.} = \frac{\text{L} \times \text{B}^3}{\text{L} \times \text{B} \times 12 \times x} = \frac{\text{B}^2}{12x} = \tfrac{1}{3}x$$

$$\therefore \tfrac{1}{3}x = \frac{2 - x}{2}$$

$$2 = 6x - 3x^2$$

$$\tfrac{2}{3} = -2x + x^2$$

add 1 to complete square

$$\tfrac{1}{3} = x^2 - 2x + 1$$

$$\tfrac{1}{3} = (x - 1)^2$$

$$\pm\sqrt{\tfrac{1}{3}} = x - 1$$

$$\pm\sqrt{\tfrac{1}{3}} + 1 = x$$

$$0{\cdot}577 + 1 = 1{\cdot}577 = x$$

$$\text{or } 1 - 0{\cdot}577 = 0{\cdot}423 = x$$

$$\therefore \text{specific gravity} = \frac{0{\cdot}423 \times 2}{2 \times 2} \text{ and } \frac{1{\cdot}577 \times 2}{2 \times 2}$$

$$= 0{\cdot}2115 \text{ and } 0{\cdot}7885$$

CHAPTER VI.

ON CENTRE OF GRAVITY OF SHIP'S HULL—INCLINING EXPERIMENT—TRIM—LAUNCHING CALCULATION.

THE centre of gravity of the stowed ship is a variable point, altering with every arrangement of the stowage, and altering with every cargo. The C.G. can be found in any fixed condition by actual experiment or by calculation. As the weight of the hull is constant, its C.G. is also constant; and knowing this point subsequent C.G.'s for other conditions can be easily determined.

Vertical C.G. by Calculation.—Items of continuous structure only are considered first, such as frames, beams, keelsons, decks, shell, floors, etc. The weight of one frame space of these is calculated for various sections throughout the length, and also the centre of gravity of each section. A curve of weights is now drawn, and also a curve of heights of C.G.

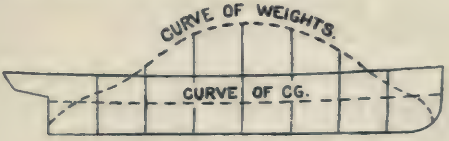


FIG. 58.

These curves are now divided to suit Simpson's rules. The weight of each section is taken and put through S.M., and the products are then multiplied by the height of the C.G. at each section. The products and moments are now summed up, and the moments divided by the products gives the height of the C.G. Arrange the work in tabular form as follows:—

Ordinates.	Weight per foot.	S.M.	Products.	C.G. above keel.	Moments.
1	—	1	—	—	—
2	—	4	—	—	—
3	—	2	—	—	—
4	—	4	—	—	—
5, etc.	—	2, etc.	—	—	—
			P.		M.

$$\frac{M}{P} = \text{C.G. above keel}$$

The following are the structural items which go to make up a merchant vessel's hull :—

Keel section.	Forged slabs extending from the scarph of stem to scarph of stern-post in a bar keel arrangement. The plates, doublings, buttstraps, and rubber plates in a flat keel arrangement.
Framing section.	The frame-angles, reverse-frames, floor-plates, lugs to keelsons, web-frames, angles to intercostals or longitudinals in double bottoms which connect them to the floor, pillars and frame-doublings; all to upper deck. The beams, beam-knees, carlings and lugs, hold beams and strong beams in machinery spaces for all decks below and including upper deck.
Bulkhead section.	All plates, stiffeners, collars, boundary angle-bars, and angles to take deck plating or planking, deep web-stiffeners for all transverse watertight bulkheads below upper deck.
Keelson section.	Centre keelson-plates, and longitudinal angle-bars, side-keelson, bilge-keelson, bilge-stringer, panting stringers, and breasthooks below upper deck, longitudinals, edge-plates, and tank top plating, where double bottoms are fitted.
Deck section.	Stringers, deck-plating, hatch-coamings, gutter angle-bars, and chocks to shell, fore and aft girders under beams, doublings in way of openings, and slip iron for all decks, including upper deck and those below.

Shell section.	Sheerstrake, garboard strake where bar keels are fitted, plating between garboard and sheerstrake, doublings in way of bulkheads, doublings abreast gangways, and at bow to take chafe of anchor, slip iron all below topside plating.
Erections.	All steel work above upper deck, frames, beams, bulkheads of poop, bridge and forecastle, casings, water-tanks, vents, anchor billboards, lighthouses, boat's beams, bridges, and stern above upper deck.
Internals.	Longitudinal bulkheads, transverse bulkheads not watertight such as coal bunkers, engine seats above main structure, boiler seats, tunnels, coal shoots, fresh water tanks, auxiliary engine seats, casings below upper deck, plating on top of ceiling under hatches, steel work in chain locker, shaft tubes in twin screw steamers.
Masts.	Plates, tee bar or angle stiffeners, required in the construction of bowsprit, masts, and yards.

Out of the total weight of steel for the whole ship from 70 to 80 per cent. is taken up with main structure, viz. keel, framing, beams, keelsons, deck and shell plating. The remaining 30 to 20 per cent. represents weights for other sections named. Of the weights of main structure referred to about 40 per cent. is required for the shell, 15 to 20 per cent. for deck plating, 11 to 13 per cent. for keelsons (when ordinary floors are fitted), 20 to 23 per cent for frames, 6 to 7 per cent. for beams, and about $1\frac{1}{2}$ to 2 per cent. for keel. These are percentages of the 70 to 80 per cent.

The following are percentages of total angles and plates for ordinary vessels of about 400 feet long and 0·75 coefficients, built to Lloyd's 100 A1 three-deck class, with deep framing in lieu of hold beams, and double bottoms fitted. C steamer is to British Corporation highest class, but otherwise similar to A and B steamers.

Items.	A steamer.	B steamer.	C steamer.
	Per cent.	Per cent.	Per cent
Main frames and reverses	7·5	7·6	7·2
Tank frames and reverses	2·1	2·2	1·5
Connecting angles, etc., in tank	1·8	2·0	1·7
Hatches	1·7	1·3	3·2
Side keelsons	4·4	6·2	3·8
Main-deck plating	5·8	5·8	6·2
Upper-deck "	6·9	6·3	6·3
Main-deck beams	3·3	2·7	2·2
Upper-deck "	2·2	2·2	1·8
Casings	2·4	1·7	2·4
Floors and intercostals	10·4	10·0	7·8
Centre longitudinal and margin plate	1·8	1·7	1·7
Tank top	4·8	4·6	3·5
Tunnel	1·6	2·1	1·9
Bulkheads	4·8	4·2	3·0
Shell	26·8	26·4	26·6
Erections	3·3	3·9	5·8

Other percentages not included in above are made up of small sundry items.

The items of continuous structure having been accounted for in the curve of weights, other items are accounted for as follows:—

Items.	Weight.	Lever above base.	Moment.
Hull	—	—	—
Bulkheads	—	—	—
Winches	—	—	—
Web-frames	—	—	—
Engine seating	—	—	—
Etc., etc.	—	—	—
Light weight =	W.		M.

$$\frac{M}{W} = \text{final C.G. of hull vertically}$$

The horizontal C.G. of hull is found by assuming curve of weights as an ordinary water-plane, and finding its C.G. in a fore-and- aft direction, as previously explained, using for lengths of ordinates weights of ordinates.

THE INCLINING EXPERIMENT.

This experiment is to determine from the actual floating vessel the C.G. as the vessel sits. It is usual to wait until the ship is as near completion as possible before inclining her, in order that the correction for "light ship" condition shall be as little as possible. "Light ship" condition means vessel in finished condition, ready for sea, with water in boilers at working level, water in condenser, with no coals, steward's or consumable stores, but with all stores supplied by builders, and spare gear to be carried on ship. In other words, the hull complete, with masts, spars, rigging, boats, carpenter's and boatswain's stores, sails, awnings, galley outfit, steward's outfit (but no consumable stores or fresh water), life-saving appliances, bedding, machinery complete, with water in boilers at working level and condenser full, condenser pipes and spare gear. All other weights should be considered as deadweight. The following notes have to be attended to:—

1. Take draught of water forward and aft.

2. See that the ballast tanks are either full or empty.

3. See that the surface of any coal in bunkers is trimmed level so that its weight and position of C.G. can be found.

4. Note the weights and positions of C.G. of all items to go on board to complete the vessel's equipment, and of all items which do not belong to the vessel, such as plant, tools, etc., and of all items belonging to the ship which are not in their proper position. In the latter case note the distance through which weights have to be moved to get final position.

5. See that all bilge-water is removed.

6. See that the vessel is not locked between another vessel and the quay wall.

7. See that the moorings are left easy.

8. All boats must be lashed down.

9. Water in boilers should be at working level and condensers full.

10. Gangways should be taken ashore.

11. If the vessel is a small one, be careful to have no more men than absolutely necessary, and to keep them in one position, except when shifting weights.

12. Sufficient weights should be placed on board to give a deviation of from 6 to 9 inches off the plumb.

13. Have at least two plumb-lines, and in large ships have three.

14. Take a note of engineer's spare gear.

Set up the plumb-lines, one amidships and one at either end. The forward line put down the fore end of the forward hatch. The midship line put down the stoke-hole from the top of the casing. The after line put down the aft side of the after hatch. The lines should be of wire that there will be no trouble with stretching. The plumb-weight at the end of the line should be suspended in a pail of water, as this eliminates to a great extent vibration. A board has to be laid in the hold, along the face of which the plumb-line will swing and the measurements be taken. The weights required will vary from 2 tons to 50 tons, according to the stiffness of the vessel. This 50 tons would be an extraordinary weight, requiring special arrangements for moving across deck, and the only time the writer has known it to be used in the merchant service was in the case of a large cargo boat with over 3000 tons of coal in the holds. In the Admiralty 50 tons is often used. For passenger boats with an easy roll 10 tons is sufficient. For large, stiff cargo boats 20 tons is sufficient in the approximate light condition. The heel required is two degrees at least.

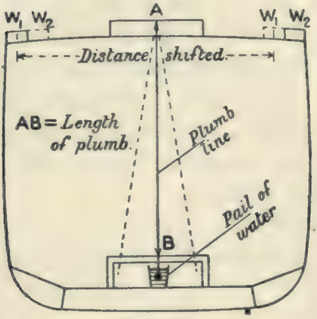


FIG. 59.

Measure length of plumb-line A to B, measure distance between weights. Have men in position, and when everything is settled mark position of plumb-line at B.

Shift weights from starboard to port, and mark position of plumb-line now, and take note of deviation in book.

Shift W to its former position, and see if plumb-line falls true, and if not take new deviation in book.

Shift W_2 to port. Note deviation. Take W_2 back to its original position, and see if plumb-line again falls true, and if not take new deviation.

Handy weights for shifting are blocks of iron with sunken handles at both ends, and weighing, say, 100 lbs. or 1 cwt. each. Or small bogies may be made to contain, perhaps, half a ton, and these are wheeled across deck. Other methods will suggest themselves, but the blocks of 100 lbs. each find most favour.

$$\text{G.M.} = \frac{\text{W} \times \text{distance}}{\text{displacement}} \times \frac{\text{AB}}{\text{BE}}$$

Displacement includes weights and men on board.

AB = length of plumb-line
BE = deviation
W = weights shifted
Distance = distance of weights shifted

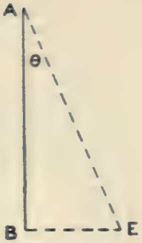


FIG. 60.

Example—

No. 1, inclination P. to S. $7\frac{1}{2}$ inches.
„ 2, „ weight as at first $7\frac{3}{8}$ „
„ 3, „ S. to P. $7\frac{5}{8}$ „
„ 4, „ weights as at first $7\frac{1}{2}$ „

4)30

Mean $7\frac{1}{2}$ inches

$$\text{G.M.} = \frac{\text{W} \times \text{distance}}{\text{displacement}} \times \frac{\text{AB}}{0{\cdot}625 \text{ feet } (7\frac{1}{2} \text{ inches})}$$

Having found the G.M. in this condition, the C.G. may be found, as it is presumed the metacentre has already been calculated. Having the C.G., the longitudinal G.M. and the moment to trim can also be determined. From this the horizontal C.G. as ship is floating can be found. The displacement and C.B. are taken from the displacement sheet. If the vessel is trimming exactly to the way the sheet worked, then the C.G. will be immediately over the C.B. If, however, the vessel is trimming by the bow or stern, the following correction has to be made: $\frac{\text{trim in inches} \times \text{moment to trim 1 inch}}{\text{displacement}}$ = shift of the C.B. forward or aft, according as vessel is trimming.

Example—

C.B. aft of C.B.P. from displacement sheet = 4·5 feet
shift of C.B. aft due to vessel trimming 6 inches by stern where inclined } = 0·8 „
C.B. or C.G. aft of C.B.P. in feet = 5·3 „

Now correct C.G. vertically and horizontally due to weights to be put on board, weights to be taken out of ship, and weights which require to be shifted in ship, etc.

1. Items to come out to obtain Light Weight.

Items.	Above keel.			About C.G. longitudinally.			
				Levers.		Moments.	
	Weights.	Levers.	Moments.	Forward.	Aft.	Forward.	Aft.
Inclining weights	—	—	—	—		—	
Men	—	—	—	—		—	
On upper deck .	—	—	—		—		—
On main " .	—	—	—		—		—
In hold	—	—	—		—		—
Coal	—	—	—	—		—	
Water	—	—	—		—		—
	w.		M.			M.forwd.	M. aft

Displacement as observed from draught $= W$

$$\frac{M}{W - w} = \text{fall of C.G.}$$

Deduct fall of C.G. due to taking out weights, which gives new vertical C.G.

$$\frac{\text{M. aft} - \text{M. forwd.}}{W - w} = \left\{\begin{array}{l}\text{forwd. shift of}\\ \text{C.G., assuming M. aft}\\ \text{the greater}\end{array}\right.$$

Deduct shift of C.G. forward from C.G., which gives new longitudinal C.G.

2. Weights to go on Board to obtain Light Weight.

Items.	Above keel.			About C.G. longitudinally.			
				Levers.		Moments.	
	Weights.	Levers.	Moments.	Forward.	Aft.	Forward.	Aft.
Joiner's work . .	—	—	—	—		—	
Carpenter's work	—	—	—	—		—	
Sails, etc. . . .	—	—	—	—		—	
Galley utensils .	—	—	—		—		—
Steward's stores .	—	—	—		—		—
Boats	—	—	—		—		—
Displacement as before $(W - w)$ . .	—	—	—				
	*		M.			M.forwd.	M. aft.

* will now be the light weight.

$$\frac{M}{\text{light weight}} = \text{C.G. above keel}$$

$$\frac{\text{M. aft} - \text{M. forwd.}}{x} = \left\{\begin{array}{l}\text{shift of C.G.}\\ \text{aft, assuming M. aft}\\ \text{the greater}\end{array}\right.$$

$x =$ weight in tons of items to go on board subtracted from the displacement as inclined.

The shift of C.G. will be measured from the new C.G., as found on previous page.

3. Weights to be shifted.

Items.	Above keel.			About C.G. longitudinally.			
				Levers.		Moments.	
	Weights.	Levers.	Moments.	Forward.	Aft.	Forward.	Aft.
Hawsers . . .	—	—	—	—		—	
Steward's outfit .	—	—	—		—		—
Upholstery . .	—	—	—		—		—
Light weight =	W.		− M. + M.			M.forwd. M. aft	M. aft
			W) ± M.	W)M.			
			Rise or fall of C.G.			Shift of C.G. forward or aft	
This rise or fall added to or deducted from previous C.G. gives final vertical C.G.				This shift of C.G., measured from previous C.G., gives final longitudinal C.G.			

Having found the C.G. of the ship in light condition, it is easy to find C.G. in any condition of ballast or lading. The C.G. of midship cargo holds may be found by taking C.G. of mean section. For forward and after holds take, say, three sections, each bulkhead and mid-length of hold. Get areas and C.G. of each. Put areas through Simpson's multipliers, and then multiply by C.G. The sum of the moments divided by the sum of the products gives the C.G. of the hold.

Other items arrange in tabular form—

Items.	Weights.	Levers above base.	Moments.
Hull and machinery .	—	—	—
Cargo in 1st hold . .	—	—	—
„ 2nd „ . .	—	—	—
„ 3rd „ . .	—	—	—
„ 4th „ . .	—	—	—
Stores	—	—	—
Bunkers	—	—	—
Water ballast	—	—	—
Fresh water	—	—	—
	W.		M.

$$\frac{M}{W} = \text{height of C.G. of laden ship}$$

The horizontal C.G. is found in a similar manner.

Items.	Weights.	Levers about midships.		Moments.	
		Aft.	Forward.	Aft.	Forward.
Hull and machinery . .	—	—		—	
Cargo in 1st hold . . .	—		—		—
„ 2nd „ . . .	—		—		—
„ 3rd „ . . .	—	—		—	
„ 4th „ . . .	—	—		—	
Stores forward	—		—		—
„ aft	—	—		—	
Bunkers	—		—		—
Water ballast forward . .	—		—		—
„ „ aft . . .	—	—		—	
Fresh water	—	—		—	
	W.			M. aft	M. forwd.

$$\frac{\text{moments aft} - \text{moments forward}}{\text{W}} = \text{C.G. aft of midships}$$

assuming moments aft to be the greater.

TRIM.

When a vessel's draught is, say, 10 feet forward and 10 feet aft, she is said to be floating on an even keel. When the draught is, say, 9 feet forward and 11 feet aft, she is said to be trimming 2 feet by the stern. The mean of 9 feet and 11 feet give the draught of 10 feet; so that a vessel which has a mean draught of 10 feet, and a lead aft or a trim of 2 feet, really lifts 1 foot at the bow and sinks 1 foot at the stern. A vessel's trim is the difference between the draughts forward and aft. If a vessel is floating on an even keel, and the captain wants her to trim, say, 2 feet by the stern, the easiest way to do this would be by taking a weight from the fore end and placing it in the aft end. By actual experiment it would be easy for him to take several weights and move them aft, until his vessel was in the required trim; but if he knew what weight was required to be moved to trim her 1 inch, he has at once, by multiplying this weight by 24, the amount required to be shifted. This figure would be in foot-tons, for it is obvious that moving 2 tons 100 feet would have the same effect as moving 5 tons 40 feet, for both have the same moment, namely, 200 foot-tons. To change the trim 1 inch the moment is called—

Moment to alter trim 1 inch, or—

Moment to trim 1 inch, and the formula is—

$$\text{Moment to trim 1 inch} = \frac{\text{displacement} \times \text{longitudinal G.M.}}{\text{length of vessel in feet} \times 12}$$

In this equation the displacement and the length of the vessel is known. The longitudinal G.M. requires to be calculated. The C.G. of the vessel is assumed to be known. The C.G. for almost all vessels is above the C.B. The G.M therefore is the B.M. – B.G. The unknown quantity in the equation now becomes B.M. In transverse B.M. it is found that G.M. $= \frac{I}{V}$. The inertia of the water-plane was calculated about the centre line as an axis. This centre line was also the C.G. of the plane transversely. The longitudinal B.M. also is $= \frac{I}{V}$. In this case the moment of inertia of the water-plane requires to be calculated about an axis at right angles to the centre line. The axis usually assumed is the midship ordinate. But this midship ordinate may not be the C.G. of the plane in a fore-and-aft direction. Moment of inertia must be calculated about the C.G., or, if not, a correction must be made. The correction necessary is to deduct from the I. about midship ordinate Ay^2. A is the area of the water-plane, y is the distance between the midship ordinate and the actual C.G. of the plane.

$$\therefore \text{longitudinal B.M.} = \frac{\text{I.} - Ay^2}{V}$$

Arrange the work in tabular form as follows:—

Ordinates.	Half-breadths.	S.M.	Functions of areas.	Levers about midships.	Functions of moments.	Levers about midships.	Functions of inertia.
1	—	1	—	4	—	4	—
2	—	4	—	3	—	3	—
3	—	2	—	2	—	2	—
4	—	4	—	1	—	1	—
5	—	2	—	0	M.	0	—
6	—	4	—	1	—	1	—
7	—	2	—	2	—	2	—
8	—	4	—	3	—	3	—
9	—	1	—	4	—	4	—
			A.		M.		S.

$$\text{Area} = \text{A} \times \tfrac{1}{3}\,\text{C.I.} \times 2 \text{ for both sides}$$

$$\text{C.G. aft of No. 5} = \frac{\text{M.aft} - \text{M.forwd.} \times \text{C.I.}}{\text{A.}} \text{ (assuming M.aft the greater)}$$

$$\text{I. about No. 5} = \frac{\text{S} \times \text{C.I.}^3 \times 2 \text{ for both sides}}{3}$$

$$\text{I. about C.G. of W.P.} = \left\{ \begin{array}{l} \text{L. about No. 5 ordinate minus \{area} \\ \quad \times \text{(C.G. from No. 5)}^2\text{\}} \end{array} \right.$$

The moment to trim ship 1 inch was stated to be—

$$\frac{\text{displacement} \times \text{longitudinal B.M.}}{\text{length of vessel in feet} \times 12}$$

This equation can now be solved for the water-line at which the B.M. has been calculated. By getting the moment to trim 1 inch for several draughts, and setting these out to scale, a curve of moments to trim 1 inch can be drawn, and the moment at any required draught readily determined.

Calculation of Changes of Trim.

In the first place, place the weight on board so that the trim is not affected (over the C.B.).

Find what increase of draught this gives. Next find the locus of longitudinal C.B. at this trim. If there is much difference between the areas of the water-lines at the old and new draughts, the vertical C.B. of the zone will require to be found.

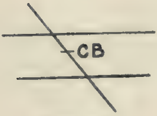


Fig. 61.

C.B. is vertical C.B. of zone (zone is the displacement bounded by the two W.L.), and the line through C.B. is the locus of longitudinal C.B.

This C.B. of zone is found by dividing the line of locus of C.B. between water-lines in the inverse proportion of the area of the water-lines.

Now shift the weight forward or aft to the position you wish.

Let d be the distance forward or aft of this vertical C.B. now found, which the weight is required to be moved;

w represents the weight in tons;

T = moment to trim ship 1 inch.

Then $\frac{wd}{\text{T}}$ = number of inches the trim is really changed

The water-planes W_1L_1 and W^1L^1 intersect in their centres of gravity. Call this B. Then the change of trim varies as—

$$\frac{wd}{T} : W^1L^1 :: W_1W^1 : W_1B :: L_1L^1 : L_1B$$

$$\therefore W_1W^1 = \frac{wd}{T} \times \frac{W_1B}{W^1L^1}$$

$$\text{and } L_1L^1 = \frac{wd}{T} \times \frac{L_1B}{W^1L^1}$$

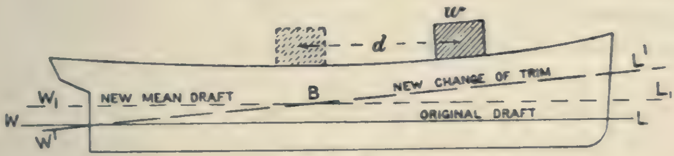


Fig. 62.

This proportions the change of trim at each end to its distance from the C.G. of the water-plane.

Let A = the original draught aft.

$$\text{Then the new draught aft} = A + \frac{w}{t_1} - \frac{wd \times W_1B}{T \times W^1L^1}$$

$$\text{then the new draught forward} = F + \frac{w}{t_1} + \frac{wd \times L_1B}{T \times W^1L^1}$$

t_1 = tons per inch.

The above formula is correct if w the weight is added.

If weight is taken off, $\frac{w}{t_1}$ will be negative throughout.

If w the weight, *when added*, is placed forward of the vertical plane through the C.G. of the zone of the increased displacement, then the sign before the third term is − for aft and + for forward. If w is aft of the above plane, the sign is + for aft and − for forward.

If w when *taken off* is forward, the sign is − for forward and + for aft.

If w when *taken off* is aft, the sign is + for forward and − for aft.

Ques. What weight must be put on board, and in what position, to change the draught a definite amount?

Ans. From above the change of draught forward would be—

$$\frac{w}{t_1} + \frac{wd}{\mathrm{T}} \times \frac{\mathrm{L_1B}}{\mathrm{W_1L_1}} = f$$

$$\frac{w}{t_1} - \frac{wd}{\mathrm{T}} \times \frac{\mathrm{W_1B}}{\mathrm{W_1L_1}} = a$$

$$f - a = \frac{wd}{\mathrm{T}}\left(\frac{\mathrm{L_1B + W_1B}}{\mathrm{W_1L_1}}\right) = \frac{wd}{\mathrm{T}}$$

$$\therefore ud = \mathrm{T}\,(f - a)$$

Ques. Place a weight on board in such a position that the draught aft may be unchanged.

Ans. Change of draught aft—

$$\frac{w}{t_1} - \frac{wd}{\mathrm{T}} \times \frac{\mathrm{W_1B}}{\mathrm{W_1L_1}}$$

$$\text{then } \frac{w}{t_1} \text{ must} = \frac{wd}{\mathrm{T}} \times \left(\frac{\mathrm{W_1B}}{\mathrm{W_1L_1}}\right)$$

$$\frac{w\,l}{\mathrm{T}} = \frac{w}{t_1} \times \frac{\mathrm{W_1L_1}}{\mathrm{W_1B}}$$

$$d = \frac{w}{t_1} \times \frac{\mathrm{W_1L_1}}{\mathrm{W_1B}} \times \frac{\mathrm{T}}{w} = \frac{\mathrm{W_1L_1 \times T}}{\mathrm{W_1B} \times t_1}$$

LAUNCHING CALCULATION.

A launching calculation determines (1) whether the vessel is inclined to tip in launching; (2) the weight on the fore poppets. As the ship slides off the ways and takes the water, the further she slides in, the greater the supporting force becomes until at last the amount of after body in the water gives her sufficient buoyancy to make her tend to lift by the stern. If there is not this buoyant tendency, but, instead, the ship still sinking deeper as she slides, there will be a certain point in the launch where the vessel is exactly balanced over the end of the ways. That is, half the weight is in the water, and half is on the ways. The water half is still not buoyant, not tending to rise. It is clear that a further slide of, say, a foot will throw the excess of weight on the water end, and this end will immediately sink in the water until it obtains sufficient buoyancy to carry its weight. The end of the standing ways is the fulcrum, and two things are now likely to happen. This fulcrum may give way, that is, the standing ways may break or spread out. If this does not occur, and the standing ways are able to take the strain, the fore end will immediately rise in the air off the ways. The aft end may not require to sink very much to get the required buoyancy, and the ship will with every foot additional slide begin to rise aft. This will bring the fore end down again on the standing ways, but meanwhile the shoring between the ship and the sliding ways may have got loose, and the sliding will not fall true on the standing ways. This may result in the vessel what is called "sticking on the ways," that is, remaining partly in and partly out of the water. By the launching calculation this probability of tipping can be determined and means taken to prevent it.

Assuming now that the vessel has no tipping moment, but gradually lifts aft as she launches, it will be seen that when she is almost entirely in the water, say, when the fore poppet is over the end of the standing ways, the force of buoyancy pressing upward will react at this fore poppet and cause a tremendous downwards pressure on the standing ways. This pressure may—

1. Spread out the standing ways.
2. Break the fore poppets.
3. Crush in the bows of the vessel.

By means of the launching calculation this pressure can be determined, and the standing ways, fore poppets, and the bows made strong enough to resist it.

Find the declivity of the ship on the ways. Find the declivity of the launching ways. Also, find the position of the upper line of the standing ways from the keel of the ship.

Find amount of water expected on day of launch.

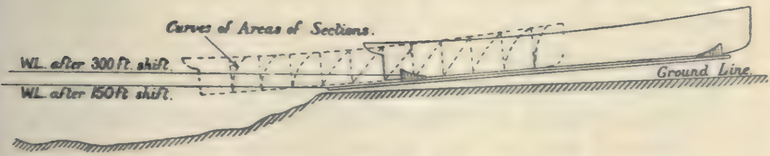


FIG. 63.

Make tracing of ship on a small scale. Divide ship into displacement ordinates. Calculate the area of each section up to the several water-planes, and draw curves of areas at each section.

Arrange for shifts, that is, the different position of ship during launching.

Shift tracing to first shift on drawing (say, 250 feet), and find the volume of displacement of ship in water now, and the position of the C.B. from the A.P., or after perpendicular. Do likewise for 300-feet shift, 350-feet and 450-feet shifts.

Estimate the longitudinal position of C.G. of ship from data for previous ships. Draw a set of curves.

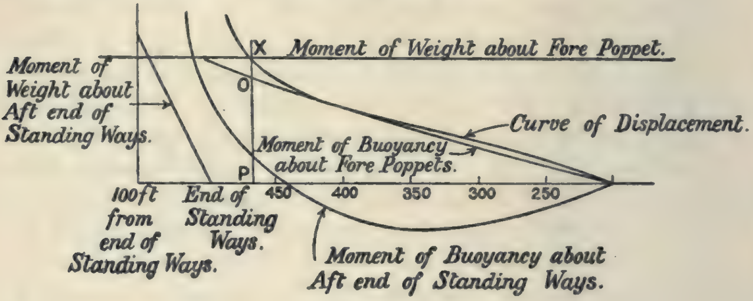


FIG. 64.

Set up to scale the moment of weight about the fore end of sliding ways or fore poppet. This is obtained by multiplying the weight of the ship by the distance of the C.G. from the fore end of ways. Next find the moment of buoyancy about the fore end of the ways. This is obtained from the equation—

$$\text{Moment of buoyancy about the fore end of ways} = \frac{\text{volume of displacement} \times \text{C.B. from fore end of ways}}{35}$$

Do this for each shift.

Set both of these curves to the same scale. Where the moment of weight and the moment of buoyancy cross each other is where the ship will commence to rise.

Set up the displacement at each shift and draw the curve. Find displacement at the point where the ship commences to rise. The difference between the displacement of ship in the water, and the displacement where vessel starts to rise, gives the weight bearing on the fore poppet. Find the moment of weight about aft end of standing ways. Also find the moment of buoyancy about aft end of standing ways for each shift. Draw curves. If curve of moment of buoyancy cuts curve of moment of weights about aft end of standing ways, there will be a tipping moment; but when they do not cut there is a lifting moment. The different shifts are obtained by shifting the C.G. of the vessel so many feet aft. The moment of weight about the after end of the ways is calculated by multiplying the weight of the ship by the distance of the C.G. from the end of the ways at the different shifts. Thus, when the C.G. is exactly over the end of the ways, and the displacement taken at, say, 6000 tons, there will be no moment of weight about the aft end, because 6000 multiplied by the distance of the C.G. from the aft end of ways, which is 0, is equal to 0.

At the 50-feet shift the moment will be 6000 × 50 foot-tons. The moment of buoyancy is calculated by multiplying the actual displacement at the different shifts by the distance of the C.B. of these various displacements from the end of the ways. The weight on the fore poppets is obtained by reading the displacement when the ship begins to rise. The ship rises at X in the diagram. The displacement is OP; subtract OP from the displacement at the launching draft, and the difference will be the weight on the fore poppets. The declivity of the ways should be from $\frac{9}{16}$ inch in large ships to $\frac{7}{8}$ inch in small ships to the foot. The camber for a large ship is from 12 inches to 15 inches. A minimum G.M. of 1 foot should be provided in the launching condition.

$$\text{The tipping lever} = \frac{\text{tipping moment}}{\text{weight of ship}}$$

The tipping lever divided by the length of ship should have a certain ratio. If this ratio is over $\frac{1}{11}$, there is likely to be trouble. A ship with $\frac{1}{8}$ has tipped. A ratio of $\frac{1}{18}$ is quite safe. The following particulars of actual launches will be found useful:—

	Weight of ship.	Length.	Declivity of ways per foot.	Declivity of keel per foot.
	tons	feet	inch	inch
A	200	200 (P.S.)	$\frac{3}{4}$	$\frac{11}{16}$
B	1000	280	$\frac{9}{16}$	$\frac{1}{2}$
C	2200	300	$\frac{9}{16}$	$\frac{9}{16}$
D	4000	430	$\frac{1}{2}$	$\frac{1}{2}$
E	5000	460	$\frac{1}{2}$	$\frac{15}{32}$
F	7000	500	$\frac{9}{20}$	$\frac{9}{20}$

"A" ship was tried with $\frac{5}{8}$ declivity in a sister ship, but was a very slow launch, 12 to 13 feet per second velocity. Had no camber.

"B" ship has 6-inch camber on a length of 300 feet. Velocity of 15 to 17 feet per second launching.

"C" ship had 9-inch camber on a length of 400 feet. Velocity 18 feet per second leaving ways.

"F" ship had 14-inch camber; length of ground-ways, 560 feet; velocity leaving ground, 15·6 feet per second; maximum velocity, 17 feet per second.

Giving camber to ways prevents them from going hollow if ground at all sinks. The bearing surface of the ways should not exceed 2 to 3 tons per square foot. Grease will bear much less before firing in summer than in winter. The standing ways require to be greased from a week to a month before the launch, as the sliding ways have to be built on top. The tallow or other composition is laid on, perhaps, $\frac{1}{8}$ or $\frac{1}{4}$ inch thick, and left for a day to harden before laying the sliding ways. The ends of the standing ways left bare are coated with black soap on the day of the launch.

High tide is sometimes not essential, as the boat, through not rising rapidly aft in launching, does not have the strain on the fore part so long a time. Where there is a danger of tipping which cannot be avoided, a good declivity of ways giving vessel plenty of speed will carry her over the danger point.

The ways must be kept in the same plane.

QUESTIONS ON CHAPTER VI.

Ques. A vessel's displacement is 5000 tons. A weight of 60 tons is moved across the deck transversely 30 feet. What is the movement in feet of G.?

Ans.

$$\frac{\text{W} \times \text{distance}}{\text{displacement}} = \frac{60 \times 30}{5000} = 0{\cdot}36 \text{ foot}$$

Ques. A vessel of 8520 tons total displacement has consumable stores on board of 1380 tons. 780 tons of these stores are situated with their common C.G. 2 feet 5 inches below the C.G. of the ship and lading, and the remaining 600 tons have their common C.G. 0·6 foot above the C.G. of ship and lading. Find how much C.G. of ship rises or falls after all stores have been consumed.

GG_1 = shift of gravity in feet.
W = weight of ship in tons.
gg_1 = distance weight moved in feet.
w = weight moved in tons.

(1) Take the 600 tons out, acting at a leverage of 0·6 foot above the C.G. of vessel.

$$\text{Formula} = GG_1 \times W = gg_1 \times w$$
$$8520 - 600 = 7920 \text{ tons}$$
$$GG_1 = \frac{0{\cdot}6 \times 600}{7920} = \frac{360}{7920} = 0{\cdot}045 \text{ foot}$$

So that taking the 600 tons out of the vessel will lower the C.G. 0·045 foot.

(2) Take the 780 tons out of ship, acting at a leverage of 2 feet 3 inches below the original C.G. of the vessel.

$$2 \text{ ft. } 5 \text{ in.} - 0{\cdot}045 = 2{\cdot}255 \qquad GG_1 \times W = gg_1 \times w$$
$$8520 - 1380 = 7140 \qquad GG_1 = \frac{780 \times 2{\cdot}255}{7140} = 0{\cdot}246 \text{ foot}$$

So that taking the 1380 tons out raises the C.G. 0·246 foot. *Ans.*

Ques. A weight of 60 tons is moved across a ship's deck 30 feet, causing an inclination of 5°. Displacement is 5000 tons. Find G.M. Tan 5° = 0·087489.

Ans.

$$\frac{W \times \text{distance}}{\text{displacement} \times \tan} = \frac{60 \times 30}{8000 \times 0{\cdot}087489} = \frac{1800}{699{\cdot}92} = 2{\cdot}57 \text{ feet G.M.}$$

Ques. Write down and explain the formula for calculating the height of longitudinal metacentre above the centre of buoyancy. What is this height in a vessel of 1130 tons displacement, the half-ordinates of L.W.P. of which are 10 feet apart and are, 6·3, 10·4, 13·3, 15·4, 16·7, 17·5, 17·9, 18, 18, 17·8, 17·4, 16·6, 15·5, 13·9, and 10·1 feet in length respectively?

$$\text{Height of M. above B.} = \frac{I}{V}$$

I = Moment of inertia of the L.W.P. of the vessel about a transverse axis through the centre of flotation.

V = Volume of the load displacement.

No. of half-ordinates.	Half-ordinates.	S.M.	Functions.	Levers.	Multiples.	Moments for inertia.	Functions for inertia.
1	6·3	1	6·3	7	44·1	7	308·7
2	10·4	4	41·6	6	249·6	6	1497·6
3	13·3	2	26·6	5	133·0	5	665·0
4	15·4	4	61·6	4	246·4	4	985·6
5	16·7	2	33·4	3	100·2	3	300·6
6	17·5	4	70·0	2	140·0	2	280·0
7	17·9	2	35·8	1	35·8	1	35·8
8	18·0	4	72·0	0	949·1	—	—
9	18·0	2	36·0	1	36·0	1	36·0
10	17·8	4	71·2	2	142·4	2	284·8
11	17·4	2	34·8	3	104·4	3	313·2
12	16·6	4	66·4	4	265·6	4	1062·4
13	15·5	2	31·0	5	155·0	5	775·0
14	13·9	4	55·6	6	333·6	6	2001·6
15	10·1	1	10·1	7	70·7	7	494·9
			652·4		1107·7		9041·2
			20		949·1		
			3)13048		158·6 excess moment		

Area of L.W.P. = 4349·7

$$\left.\begin{array}{l}\text{Distance of centre of flotation from}\\ \quad\text{No. 8 ordinate}\end{array}\right\} = \frac{158\cdot6}{652\cdot4} \times 10 = 2\cdot4 \text{ feet}$$

$$\text{moment of inertia about No. 8 ord.} = (9041\cdot2 \times 10^2 \times \tfrac{10}{3} \times \tfrac{2}{1})$$

$$\text{moment about centre of flotation} = (9041\cdot2 \times 10^2 \times \tfrac{10}{3} \times \tfrac{2}{1}) - (4349 \times 2\cdot4^2)$$

$$= 6027466 - 25050 = 6002416$$

$$\text{longitudinal B.M.} = \frac{6002416}{1130 \times 35} = 151\cdot7 \text{ feet}$$

Ques. A ship passes from sea to river water. Show how an estimate may be made of the change of draught. What will be the mean draught in river water of a fine ship whose mean draught in sea water is 25 feet, her length on water-line being 320 feet, breadth 48 feet, and displacement 7500 tons?

Let Δ = displacement in tons;
X = depth of layer or change in draught;
T = tons per inch in sea water.

$$\text{Tons per inch in river water} = \frac{63T}{64}$$

$$\text{volume of } \Delta \text{ in salt water} = \frac{\Delta \times 2240}{64}$$

$$\text{volume of } \Delta \text{ in river water} = \frac{\Delta \times 2240}{63}$$

$$\therefore \text{difference in volume} = \frac{\Delta \times 2240}{63} - \frac{\Delta \times 2240}{64}$$

$$= \frac{\Delta \times 2240}{63 \times 64} \text{volume of layer}$$

$$\text{weight of layer} = \tfrac{63}{64} \text{T} \times \text{X}$$

$$\text{volume of layer} = \tfrac{63}{64} \text{TX} \times \tfrac{2240}{63}$$

$$\therefore \frac{\Delta \times 2240}{63 \times 64} = \tfrac{63}{64} \text{TX} \times \tfrac{2240}{63}$$

$$\therefore \text{X} = \frac{\Delta \times 2240}{63 \times 64} \times \frac{64 \times 63}{63\text{T} \times 2240}$$

$$\text{X} = \frac{\Delta}{63\text{T}}$$

$$\text{T} = \frac{320 \times 48}{600} = \tfrac{128}{5} \text{ tons}$$

$$\text{X} = \tfrac{7500}{63} \times \tfrac{5}{128} = \tfrac{37500}{8064} = 4{\cdot}605 \text{ inches}$$

Answer = 4·605 increase.
New draught = 25 feet + 4·605 inches.

Ques. A ship 380 × 50 × 29 feet floats at a draught of 20 feet forward and 22 feet 6 inches aft; displacement, 8510 tons; G.M. 1·75 foot. The following weights are placed on board in the following positions:—

20 tons	100 feet forward of centre of flotation				
45 "	80	"	"	"	
15 "	40	"	"	"	
60 "	50 feet aft		"	"	
40 "	80	"	"	"	
30 "	110	"	"	"	

L.G.M. with weights on board, 415 feet; tons per inch, 35. Find new draughts.

Ans. (1) Assume weights placed over the C.F. of water-line.

(2) Find parallel sinkage of vessel due to weights being placed in that position.

(3) Move weights to proper positions and find moment tending to trim ship.

Mean sinkage = 20 + 45 + 15 + 60 + 40 + 30 = $\frac{210}{35}$ = 6 inches.

Forward moment.			Aft moment.		
Water-line.	Displacement.	Moments.	Water-line.	Displacement.	Moments.
20	100	2000	60	50	3000
45	80	3600	40	80	3200
15	40	600	30	110	3300
		6200			9500 aft 6200 forward

Excess aft = 3300 foot-tons

Moment tending to trim ship by the stern = 3300 foot-tons

$$\text{moment to alter trim 1 inch} = \frac{8720 \times 415}{12 \times 380} = 793{\cdot}6 \text{ tons}$$

$$= \tfrac{3300}{793} = 4{\cdot}16$$

	Draughts forward.			Draughts aft.	
	ft.	in.		ft.	in.
	20	0		22	6
Mean sinkage =		6	Mean sinkage =		6
	20	6		23	0
		$2\frac{1}{16}$			$2\frac{1}{16}$
New draught	20	$3\frac{15}{16}$ forward	New draught	23	$2\frac{1}{16}$ aft

Ques. What is meant by trim and change of trim?

Define moment to change trim.

Ans. (1) Trim is the difference between the draughts forward and aft.

(2) The change of trim is the sum of the increase in draught at the one end and the decrease in draught at the other when some alteration in ship's condition has occurred.

$$\text{Moment to alter trim} = w \times d \text{ or } GG_1 \times W$$

$$GG_1 \times W = w \times d$$

∴ either equation will give moment to alter trim

where w = weight moved (tons);

d = distance which it is moved (feet);

W = weight of ship;

GG_1 = shift of gravity of ship.

Moment changing trim is the product of the weight moved by the longitudinal distance it is moved ($w \times d$).

Moment to alter or change trim is that force expressed in foot-tons that it will take to change the trim of a vessel by adding weights towards the ends or by moving weights from one position to another longitudinally.

Ques. How would you estimate the change of trim?—

(1) When water is admitted into a double bottom until full.

(2) When compartment is partially filled and not in free communication with the sea.

(3) When compartment is bilged at the end of vessel and in free communication with the sea.

Ans. (1) If water is admitted into the double bottom until full—

1st. A certain amount of buoyancy will be lost.

2nd. Trim of vessel will be affected if it should happen to be one of the fore or after tanks, therefore the loss of buoyancy (which will be the same as adding a weight) is first calculated and increase of draught found. Now suppose we place the additional weight over centre of flotation at W.L., the vessel will sink to W_1L_1 parallel to W.L.

$$\frac{\text{weight}}{\text{tons per inch}} = \text{increase of draught}$$

Find C.G. of tank, say B. Now the weight × distance of C.G. of tank from centre of flotation $= \dfrac{\text{moment altering trim}}{\text{moment to alter trim 1 inch}} =$ sinkage at fore end and rise at after end.

(2) Compartment partially filled and not in free communication with the sea. 1st. A certain amount of buoyancy will be lost = a weight added = more displacement, hence an increase of draught. 2nd. Trim of vessel altered if one of the fore or after compartments be affected.

1st. To find increase of draught—

$$\frac{\text{weight}}{\text{tons per 1 inch}} = \text{added draught}$$

2nd. Calculate change of trim approximately, *i.e.* calculate body of water in compartment, and take distance from C.F. $= \dfrac{\text{weight} \times d}{\text{M. to alter trim 1 inch}} = x$. Change of trim $\div\ 2 =$ rise aft and sinkage forward approximately.

When the vessel is floating at water-line already found, the line at the surface of the water in tank has moved parallel to it. The centre of gravity of the tank will also have moved, since the volume of water is changed in form, therefore it will be found necessary to make another correction by taking the new distance d^1, then the change in trim will be found to be a little more forward—

$$\frac{\text{weight} \times d^1}{\text{M. altering trim 1 in.}} = \text{change of trim}$$

It will now be found that the water-line has changed again, so that the form of the water in tank has also changed; but another correction is not necessary, as the previous one is near enough. A further correction is made to find the new moment to alter trim.

$$\frac{\text{L.M.G.} \times \text{D}}{\text{L.W.L.} \times 12} = \text{new moment to alter trim 1 inch}$$

(3) Compartment bilged at end of vessel and in free communication with the sea. Trim will be altered. A certain amount of buoyancy will be lost. Part of moment of inertia of water-line will be lost.

$$\frac{\text{weight of water in compartment}}{\text{tons per inch}} = \text{increase of draught}$$

Now find moment of inertia of tank about its own axis.

Let $i =$ moment of inertia about ꝏ;
$\text{I}_1 =$ new moment of inertia;
$\text{I} =$ inertia of W.L. originally.

$$\text{Then I} - i = \text{I}_1$$

$$i = \left\{\begin{array}{l}\text{moment of inertia of tank about its}\\ \quad\text{own axis}\end{array}\right.$$

$$\text{then } i + (\text{A} \times d^2) = \text{I}$$

$$\left.\begin{array}{l}\text{moment of inertia about ꝏ} \div \text{volume}\\ \quad\text{of displacement}\end{array}\right\} = \text{M.B.} - \text{B.G.} = \text{L.M.G.}$$

$$\text{and } \frac{\text{L.M.G} \times \text{displacement}}{\text{L.W.L.} \times 12} = \text{new moment to alter trim 1 inch}$$

Ques. A ship is to be 400 feet long, the ground has $\frac{5}{8}$-inch declivity, and the launching ways $\frac{13}{16}$ inch; what would be the minimum height of the foremost block?

Ans. $x = 400 \times (\frac{13}{16} - \frac{10}{16}) = 25 \times 3 = 75$ inches.

$\therefore$ 6 feet 3 inches height of foremost block, and if allowance for 1 foot clearance, height = 7 feet 3 inches.

Ques.—The half-ordinates of the L.W.L. of a ship of 785 tons displacement are 25 feet apart, and their lengths are 0·4, 7·8, 12·5, 15·4, 16·5, 16·2, 14·8, 11·7, and 7·0 respectively. Calculate the height of the longitudinal metacentre above C.B.

(Ordinates 25 feet apart.)

No. of ordinates.	Half-ordinates of water-line.	S.M.	Functions.	Levers.	Moments.	Moments for inertia.	Products for inertia.
1	0·4	1	0·4	4	1·6	4	6·4
2	7·8	4	31·2	3	93·6	3	280·8
3	12·5	2	25·0	2	50·0	2	100·0
4	15·4	4	61·6	1	61·6	4	61·6
5	16·5	2	33·0	0	206·8	0	00·0
6	16·2	4	64·8	1	64·8	1	64·8
7	14·8	2	29·6	2	59·2	2	118·4
8	11·7	4	46·8	3	140·4	3	421·2
9	7·0	1	7·0	4	28·0	4	112·0
			299·4		292·4 206·8		1165·2

Excess = 85·6

$$\text{Area of L.W.L.} = \frac{299·4 \times 2 \times 25}{1 \times 3 \times 1} = 4990 \text{ square feet}$$

$$\text{position of centre of flotation} = \frac{85·6 \times 25}{299·4} \text{ from No. 5} = 7·15 \text{ feet}$$

$$\text{moment of inertia about No. 5} = \frac{1165·2 \times 25 \times 25 \times 2 \times 25}{1 \times 1 \times 1 \times 1 \times 3} = 12137500$$

$$\text{correction AD}^2 = \frac{299·4 \times 2 \times 25}{1 \times 3 \times 1} \times \left(\frac{85·6 \times 25}{299·4}\right)^2 = 255088$$

$$\left.\begin{array}{l}\text{Moment of inertia about centre}\\ \quad\text{of flotation}\end{array}\right\} = 11882412$$

$$\text{displacement in cubic feet} = 785 \times 35 = 2745 \text{ cubic feet}$$

$$\text{then longitudinal B.M.} = \tfrac{11882412}{2745} = 432·5 \text{ feet.} \quad \textit{Ans.}$$

Ques. Calculate the moment to alter trim 1 inch of vessel for which lengths of ordinates of water-plane are known. Let L = 98·5 feet, and B.G. = 1·75 feet.

Ans.

No. of sections.	Half-ordinates.	S.M.	Functions of ordinates.	M.L.	Moments of functions.	M.L.	Moments of moments.
1	1·00	½	0·50	5	2·50	5	12·50
1½	5·79	2	11·58	4½	52·11	4½	234·45
2	7·33	1½	10·99	4	43·96	4	175·84
3	8·83	4	35·32	3	105·96	3	317·88
4	9·37	2	18·74	2	37·48	2	74·96
5	9·50	4	38·00	1	38·00	1	38·00
6	9·50	2	19·00	0	280·01	0	—
7	9·50	4	38·00	1	38·00	1	38·00
8	8·91	2	17·83	2	35·64	2	71·28
9	7·50	4	30·00	3	90·00	3	270·00
10	4·66	1½	6·99	4	27·96	4	111·84
10½	2·58	2	5·16	4½	23·22	4½	104·49
11	0·10	½	0·05	5	0·25	5	1·25
			232·15		215·07		1450·49

Volume of displacement = 288 × 35 = 10080 cubic feet

232·15
3·28
185720
46430
69645
761·4520
2
1522·9040

Forward 215·07
Aft 280·01
Excess aft = 64·94
9·85
639·659

C.G. aft 6 = $\frac{639{\cdot}659}{232{\cdot}15}$ = 2·7

Area of W.P. = 1522·904.

Sum of moments of moments = 1450·49
⅓ C.I. = 3·28
4757·50
C.I. = 9·85
46861·3750
C.I. = 9·85
461584·4945
deduct 761·450 × 2·7² = 5550·970
moment of inertia about centre of flotation = 456011·165
2
912022·330
= $\frac{912022}{10080}$ = 90·46 feet

Long metacentre above C.B. = 90·46
B.G. = 1·75
88·71 feet

$$\text{Formula moment to alter trim 1 inch} = \frac{\text{L.M.G.} \times \text{displacement}}{12 \times 98{\cdot}5}$$

$$= \frac{88{\cdot}71 \times 288}{12 \times 98{\cdot}5} = 21{\cdot}7$$

therefore the moment to alter trim 1 inch = 21·7 foot-tons
" " " x inches = $x \times 21{\cdot}7$. *Ans.*

Ques. Describe briefly what strains you would expect to be developed in a ship during the action of launching; and what points in connection with the state of the hull does the consideration of these strains effect?

Ans. When the blocks have been knocked out from under the vessel and she rests on the launching ways, there is a tendency to alter the transverse form of the vessel owing to the parts of the bottom on either side of the ways being unsupported and the transverse forces are acting downwards with the portion supported by the ways as fulcrum. When the vessel slides down the ways and the stern hangs out over the water, and when partly submerged a hogging strain is developed, and as the vessel moves down the ways this gradually gives way to a sagging strain, owing to the after body of the ship being water-borne and the fore body supported on the ways. Just before the stem leaves the ways there is a big tendency to break the vessel at the stem foot owing to its being the only portion supported by the ways. Before launching, the important longitudinal and transverse portions of the structure should be completed and riveted up, such as beams, frames, floors, pillars, stringers, decks, double bottom, sheer strakes, etc. In a man-of-war the ways are arranged under a longitudinal, if possible, and shored up to the protective deck in a direct line. A poppet is arranged at the fore end to carry it down the ways.

Ques. Describe the launching arrangements for a steamer whose launching weight is 3000 tons, giving the inclination of the ways, the area of the sliding surface, and other important details, and give particulars of the arrangements to be made if the vessel must be pulled up within 50 yards of the end of the ways.

Ans. For a ship of 3000 tons launching weight a suitable declivity would be, say, ¾ inch per foot, and as the sliding ways should not have a pressure of more than 2 tons per square inch of sliding area, the width of ways, assuming the ship to be about 450 feet long, would be not less than

$$\frac{3000 \text{ tons}}{2 \times 450 \times 2} = 1{\cdot}67 \text{ feet}$$

If an ordinary ship, the ways should be spaced at equal distances from the centre line, and should measure about one-third of the beam of the ship from centre to centre. If the vessel is a fine one, they should be spaced slightly closer so as to better take the weight of the ship.

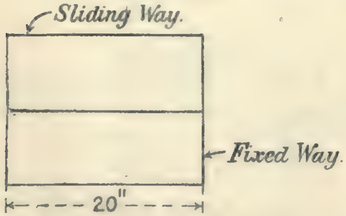


FIG. 65.

Set off the declivity of the ways at several points in the vessel's length, arranging the after end of the ways so that there is no fear of the vessel's fore foot striking the ground at that part. Fix sighting boards at each point, and by sighting get a straight line with the proper declivity. If new, the ways should have had a good quantity of tallow rubbed into the two surfaces which come in contact with each other, so that there is no likelihood of friction. Now commence to build up the ground ways, taking care to get them in a perfectly straight line on both sides of the ship and parallel to each other. A camber is usually given to the ways to prevent them sagging when the weight of the vessel is borne by them, and also to prevent the vessel getting too much speed at first, and, after she has passed the point at which is the biggest camber, to get her into the water as quickly as possible, as this reduces the period during which she is partly borne by the water and partly by the ways. The camber in this vessel should be about 16 inches, and the curve of the ways should be part of the circumference of a circle. Set off at different points in the length the correct camber, and by this means a fair surface can be obtained. By means of a long board, which butts against the inside of each set of ways and stretches athwart the vessel, and a spirit-level, you can make sure that the waves are exactly similar in camber at any point, and also that they are parallel. The ground ways should be carefully packed underneath so that they will not give under the weight of the vessel. The ground ways are firmly secured to the blocks upon which they rest by means of bent iron bars called dogs, with sharp points which are driven into each. The sliding surfaces of the ground ways are given a thorough coating of a mixture consisting of tallow, whale oil, and soft soap. The sliding ways after having been similarly treated are placed on the ground ways and secured by means of dog shores. After they are fixed, the packing up between the upper surface of the sliding ways and the bottom of the vessel should be proceeded with. Between the packing logs and the sliding ways wooden wedges should be introduced, so that the packing can be tightened up afterwards. The fore and after ends, where the vessel gets finer, should be carried by poppets, and angle bars may be riveted to the shell to take the fore poppets, or a cradle for the fore end of the vessel to rest it and carry it by the ways may be introduced. From just above the point of the biggest camber down to the after end, the ground ways should be well stayed by shores so as to check the tendency which the vessel has at these parts to tear the ways asunder, also a good number of dog shores should be fixed. The arranging of the drags should now take place, the total weight being about 5 per cent., viz. 150 tons. This weight should be equally divided each side of the ship, and the 75 tons on each side should be made up of weights at fairly regular intervals of from 20 to 30 tons, all connected to each other by means of stout wire hawser and the after one which takes the first strain connected either to

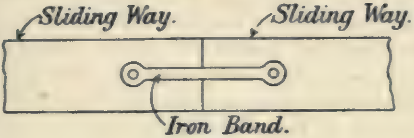


FIG. 66.

bulb angle lugs on lower bows of the vessel or run through the hawsepipes, by means of either the ship's cables or stout wire hawser. This should be supported by a number of hemp ropes from the ship's side at regular intervals, and arranged so that the first rope begins to check the vessel when she has passed the highest camber. These are fixed so that they snap, but help to gradually check the vessel's speed, and so avoid the heavy strain which would come from check. The length of the wire from the first weight should be about the distance which that weight is from the ends of the ways together with about 40 yards, which will leave about 10 yards' drag for the weights. A rope may be fixed to the stern, and also to a point up the quay, which, when the weights begin to drag, will tend to turn the vessel's stem round, and so reduce the probability of her striking the opposite side. An hydraulic jack can be got in readiness at the fore end so as to assist the vessel to move in case she does not do so at once. About an hour before the launch the ways are tightened up by means of the wedges before mentioned, to take the weight of the vessel, and the bilge shores and blocks are then knocked out. The weight of the vessel squeezes the soft soap mixture, and this removes any sticky action which it might have. When the time for launching has arrived the keel blocks are hammered out, or the wedges are split out, and the weight of the vessel is borne for a short time slowly by the dog shores until the men get from underneath the bottom. Care should be taken that this time is not too long (and also that there are a sufficiency of dog shores), or else the dog shores will get jammed. The dog shores are all connected to a trigger, which when pulled releases them simultaneously, and leaves the vessel free to glide down the ways into the water.

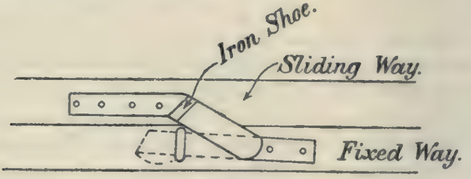


FIG. 67.

Ques. An inclining experiment was performed upon a vessel of 4000 tons displacement. 30 tons moved across 48 feet produces a shift of 15 inches upon a 10-feet pendulum. Find the G.M. at the time of the experiment.

Ans. Let W = weight moved;
D = distance through which weight is moved;
Δ = displacement in tons;
a = length of shift;
l = length of pendulum.

$$\text{Then G.M.} = \frac{w \times d}{\Delta} \times \frac{l}{a}$$
$$= \frac{30 \times 48}{4000} \times \frac{10}{1{\cdot}25}$$
$$= 2{\cdot}88 \text{ feet}$$

CHAPTER VII.

STRENGTH OF SHIP—NEUTRAL AXIS—STRENGTH OF BEAMS—RIVETS AND RIVETED JOINTS—CURVES OF STRENGTH.

Strains.—The principal strains brought on a ship are—

1. Longitudinal, or bending strains.
2. Transverse, or racking.
3. Bending, racking, or compressive strains produced by water pressure.
4. Twisting (the inequality of each transverse section to right itself when inclined).
5. Inertias of different parts of the vessel which have to be overcome when the vessel is in motion, in conformity with impressed forces from outside, causes all the other strainings to be produced.

It is in the province of the naval architect to detect and measure these strains, and so to dispose of the material at his command that the ship may be strong to resist them.

1. *Bending Strains.*—It is generally found that if we provide for the bending strains, we have strength enough to provide for all the other strains.

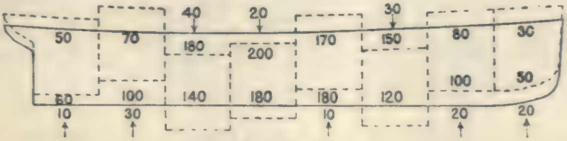


Fig. 68.

The figures along the top, but inside the figure, represent the weight of the part of the vessel. The figures along the bottom, but inside the figure, represent the weight of the volume of water displaced by the sections. The figures on the top, but clear of the figure, are the resultants, the arrows showing the direction of the force. The figures underneath are the resultant buoyancies, the arrows showing their direction. The distribution of weight and buoyancy are unequal, longitudinally, but the sum of each is equal as the ship is in equilibrium. The tendency of the sections is to sheer or slip past one another until each has adjusted itself, and each has an equal force of weight and buoyancy acting on it.

Where there is an excess of weight the section tends to sink. Where there is an excess of buoyancy the section tends to rise.

Racking Strains.—In the same way as before the unequal distribution of weight and buoyancy transversely produces a racking strain.

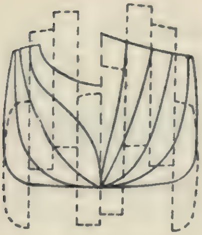


Fig. 69.

Water Pressure.—(1) There are forces due to the pressure of water on the sides, bow, and stern of a ship.

(2) There are greater strains when the ship begins to move.

The forces which move the ship act on her at some points (mast partners, thrust block, etc.).

Pitching Strains.—The forces due to pitching act on the weights piled up in the ends and cause greatly increased bending moments.

Rolling.—A greater force is necessary to set the armour of a battleship or cruiser in motion than the other parts of the ship, and correspondingly a greater resisting force is necessary to stop the rolling. This is due to the inertia of the armour due to its mass.

Twisting Inclination.—The vessel is inclined. The C.B. and C.G. are not in the same straight line and do not correspond. This causes a relative twisting of the two sections.

Curve of Buoyancy.—

$$\frac{\text{area of section} \times 1 \text{ foot}}{35 \text{ tons}} = \begin{cases}\text{tons of buoyancy or upward pressure} \\ \text{per foot of length at each section}\end{cases}$$

Set these results up from a base line, and the curve you get will represent the buoyancy of the ship.

This figure represents the upward forces due to buoyancy acting on the vessel, and the downward forces due to weight acting on the vessel. Take the section AA.

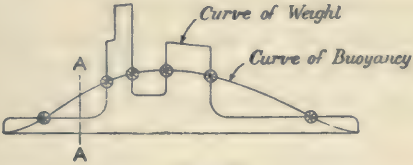


FIG. 70.

Up to a certain point the weight and buoyancy balance. Beyond that there is an excess of buoyancy. The excess of buoyancy is equal to an *opposite resistance* the structure must offer *to being pushed up.*

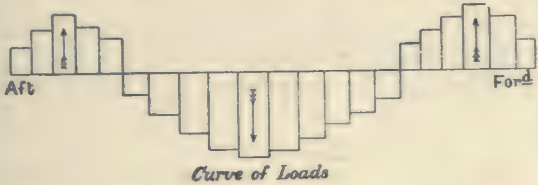


FIG. 71.

We see that in Fig. 70 there is an excess of buoyancy amidships and of weight at the end. These *unbalanced forces* are called *loads.* The above figure must be such that the area of the part below must be equal to the area of the part above the line. The C.G. and C.B. of the ship at equilibrium must be in the same straight line. We take from this a part which is common to both. The C.G. and C.B. at this part is in the same vertical straight line. The remaining part must also fulfil this condition. The C.G. of the parts above and below the line must coincide (see curves of loads) as the areas are equal.

Sheering Force.—Take two bodies connected by ties at top and bottom AB and CD; one body supported and the other

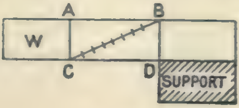


FIG. 72.

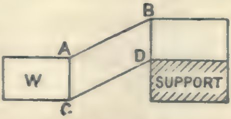


FIG. 73.

(W) hanging. Ties have frictionless hinges. If there is no other tie the body (W) will fall as in Fig. 73. But introduce a tie CB, and the body (W) will not fall. CB, *therefore, is the tie which prevents sheering.* This diagonal tie tends to develop the sheering capabilities of the structure.

Bending Moment.—If we remove the top or bottom ties, AB or CD, the body W will bend down as in Fig. 75. *The top and bottom ties develop the bending capabilities of the structure.*

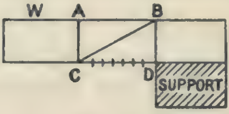


FIG. 74.

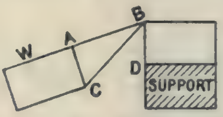


FIG. 75.

Sheering Force.—We have seen that the diagonal tie CB tends to prevent sheering. *Therefore* the *strain* on CB, which may be called (F), tends to prevent the sheering force, which is clearly (W) the weight of the hanging body.

Let F represent in magnitude and direction the strain on CB.

$$\text{Then BD} = \text{F} \cos \theta \text{ is the vertical component}$$
$$\therefore \text{BD} = \text{F} \cos \theta = \text{W} = \text{sheering force}$$

If θ becomes very small, so that $\cos \theta = 1$,

$$\text{then BD} = \text{F} \times 1 = \text{F} = \text{W}$$

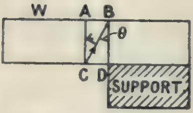


FIG. 76.

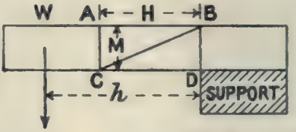


FIG. 77.

We have seen that the top and bottom ties prevent, or tend to prevent, bending. The *forces* in the top and bottom ties form a couple whose moment is H (intensity of force) × m (distance between upper and lower ties).

Hm = bending moment of ties.

But the moment which tends to produce bending is equal to—

$$\text{W} \times h \quad \therefore \text{W}h = \text{H}m$$

Let O be the point where the curves of loads intersect the base line. Introduce at O two equal and opposite forces, W_1.

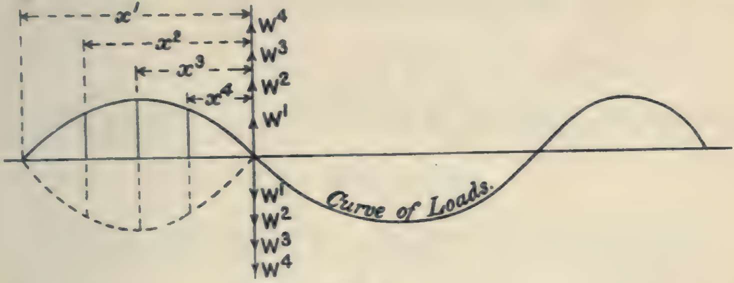


FIG. 78.

Moment of couple W_1 (at extremity) and W_1 (at O) $= W_1 \times x_1 =$ bending moment.

Similarly sheering force at O $= W_1$

Similarly the *whole bending moment* of the forces to the left of O $= W_1 \times x_1 + W_2 \times x_2 + W_3 \times x_3 + W_4 \times x_4$

Sheering forces $= W_1 + W_2 + W_3 + W_4$

Thus area of curve of loads up to any point = sheering force at the point.

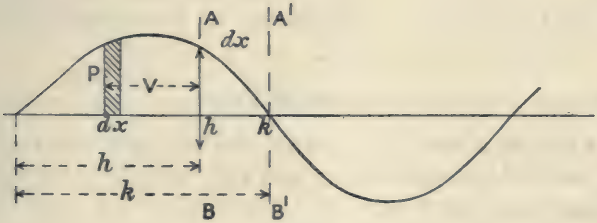


FIG. 79.

Take any section, AB, and introduce a force, Pdx, at AB acting in two equal and opposite directions at that section, and therefore balancing each other. Then the *downward force* Pdx *at* AB = *sheering force, the couple* $Pdx\ V$ = *bending moment.*

Take all the values of Pdx to the left of AB.

We thus obtain the sheering force AB.

Take all the values of $Pdx \times V$ to the left of AB.

We thus obtain the bending moment at AB.

$$\int_0^h \mathrm{P}dx = \text{whole sheering force at AB}$$
$$\int_0^h \mathrm{VP}dx = \text{bending moment of AB}$$

Take another section, A_1B_1.

$$\text{Bending M. at } A_1B_1 = \int_0^k (\mathrm{P} \times dx)(\mathrm{V} + dx) = \int_0^h \mathrm{VP}dx + \int_0^k \mathrm{P}dx - dx$$
$$\text{bending M. at AB} = \int_0^h \mathrm{VP}dx$$
$$\text{difference of B.M.} = \int_0^k \mathrm{P}dx \, . \, dx = \mathrm{M}.$$

Summation of all values of M. between O and K = total value of M.

$$\mathrm{M} = \int(\int \mathrm{P}dx)dx$$
$$\text{But } \int \mathrm{P}dx = \mathrm{F} \text{ (sheering force)}$$
$$\therefore \mathrm{M} = \int \mathrm{F}dx$$

Relations between Curves of Loads, Bending Moments, and Sheering Force.—From the preceding pages we see that the areas of the curve of loads up to any point = sheering force, and area of the S.F. curve up to any point = bending moment at that point.

Take the case of a uniform log of rectangular section 10 feet broad and 5 feet draught.

$$\text{Then the buoyancy per foot of length} = \frac{10 \times 5}{35} = 1{\cdot}43 \text{ ton}$$

As the log is *uniformly loaded*, the weight per foot of length must be 1·43 ton throughout, and the "curves" of weight and buoyancy coincide.

Therefore there is no sheering force or bending moments.

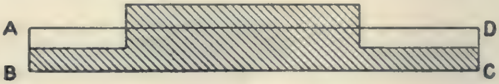


Fig. 80.

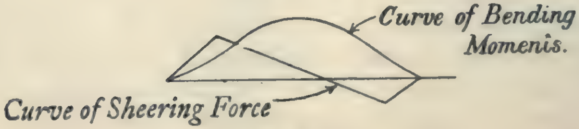


Fig. 81.

In the second case the log is loaded for half its length midship with iron, so that the load = weight of log. The shaded part would then be its curve of weights.

ABCD would then be its curve of buoyancy.

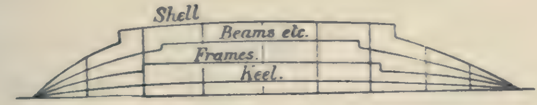


FIG. 82.

Curve of Weights.—To draw the curve of weights we divide the structure into two parts: (1) the continuous weights, *i.e.* keel framing, plating beams, etc. We determine the weights per foot of the length of these parts at different sections and draw curves. These curves are partly discontinuous as the scantlings of material vary at different places. (2) The discontinuous weights.

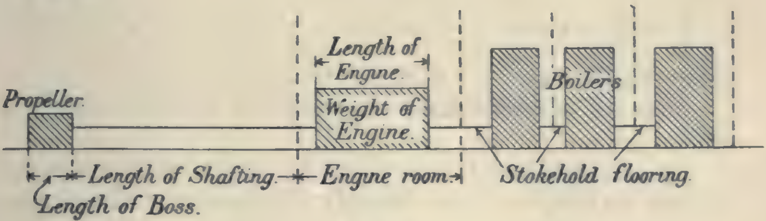


FIG. 83.

To get the weight of hull itself, take the continuous parts of hull, etc., as above.

Items of *continuous weight.*—Keel, centre keelson, side keelson, shell plating, stringers, deck plating, tank top, wood deck, ceiling, sparring, runners, etc.

Items of *transverse weight.*—Frames, reverses, floors and lugs (at every frame space), beams, pillars. *These are treated all as continuous weights.*

Items of *discontinuous weights.*—Masts, winches, deck houses, anchors and cables, pipes, cabin and cabin bulkheads, machinery, shafting, stem and stern posts, etc.

Then by dividing the volume of cargo space by the Dwt. capacity we get the number of cubic feet allowed for each ton of cargo, and can set up a curve of weights of homogeneous cargo. Curve of weights of coal is obtained in the same manner.

Curves of Weight and Buoyancy.—Where the curves cross each other are called water-borne sections. The sheering force curve reaches a maximum at one or other of these points.

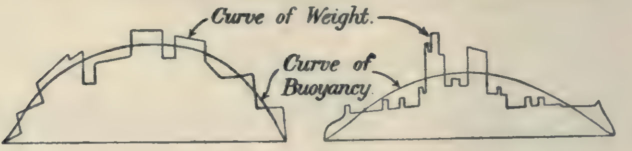


FIG. 84.

Stresses on Structures.—(1) *Tension.* Simple tension (stretching bears a definite relation to the force which causes stretching).

Let L = original length of a bar which stretches Y.

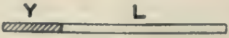


FIG. 85.

$\frac{Y}{L} = E =$ strain produced in bar, and is such that $P =$ producing force per unit of area $= c$(constant)e.

NOTE.—c is constant for any value of P not exceeding a limit.

(2) *Compression.*—Bodies which fail under compression fail in very complicated ways, entirely different from simple compressive strains.

(3) *Bending.*—Simple bending should not be combined with sheering. It is impossible to have bending without tension or compression.

If we take a bar symmetrical through its middle section and assume it to be bent into a circular arc by a uniform bending moment throughout its whole length, we have a case of simple bending. Take a homogeneous bar of uniform transverse section symmetrical about a plane through its geometrical axis parallel to the plane of bending.

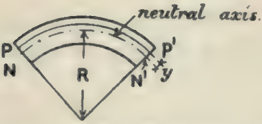


FIG. 86.

The longitudinal horizontal layers composing the bar are stretched and compressed as if they are independent of each other.

Planes before bending will remain planes after bending.

$$\text{ON} = \text{R} \qquad \text{OP} = \text{R} + \text{Y} \qquad \text{PN} = \text{Y}$$

$$\text{PP}_1 = 2\text{OP}\theta = 2(\text{R} + \text{Y})\theta$$

$$\text{NN}_1 = 2\text{ON}\theta = 2\text{R}\theta$$

Stretch of section $\text{PP}_1 = 2\text{Y}\theta$

$$\text{stretch or extension} = \frac{\text{Y}}{\text{R}} = e$$

$$\text{P} = \text{E}e$$

Formulæ— $\frac{\text{Y}}{\text{R}} = \frac{\text{P}}{\text{E}} = e; \quad \frac{\text{P}}{\text{Y}} = \frac{\text{E}}{\text{R}}$

All the forces acting on the bar on the upper side are different to those on the lower side. Let b equal breadth of section at point P. *Then* for any thickness dy between consecutive layers $\text{P} \times b \times dy$ = total force acting on a layer. $\text{P}bdy$ = force on elementary layer;

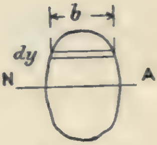


FIG. 87.

$$\Sigma \text{P}bdy = 0$$

$$\text{P} = \frac{\text{YE}}{\text{R}}$$

$$\Sigma \frac{\text{YE}dyb}{\text{R}} = \text{sum of moments of areas of cross-section}$$

Therefore the N.A. passes through the middle section.

$\frac{p}{y} = \frac{\text{M}}{\text{I}}$ is the formula connecting the intensity of the force caused by the bending with the bending moment, and with the size and scantling of the structure.

To find the Neutral Axis.—

I_0 = value of I. in $\frac{p}{y} = \frac{\text{M}}{\text{I}}$

= M.I. about an axis through the C.G., *i.e.* N.A.

Firstly, take any axis AB for an axis of moments.

Let $dxdy$ = elementary area.

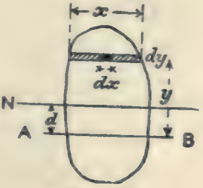


FIG. 88.

$$\begin{aligned} \text{Then } y^2dxdy &= \text{elementary moment inertia} \\ \int\!\!\int y^2dxdy &= \text{moment of inertia about AB} \\ \int\!\!\int ydxdy &= \text{moment of area} \\ \int dxdy &= \text{area} \\ \text{then } \frac{\int\!\!\int ydxdy}{\int dxdy} &= \text{distance of NA from the axis you have taken} \end{aligned}$$

Call this distance d. Then I_0 (M.I. about NA) $= I - Ad^2$. In doing this for an actual ship assume your axis at four-tenths the moulded depth, and find the M.I. above and below, and combine.

To find the supporting force in tons per foot of length. As the supporting force acts vertically, divide the ship into suitably placed vertical sections. Take the area of the L.W.L. of each section × 1 foot of length, and divide this product by 35.

Set these up and draw a fair line through the supporting force at any section $= \dfrac{\pi r^2}{2 \times 35}$

Now, $r = clr^2 = c^2l^2$

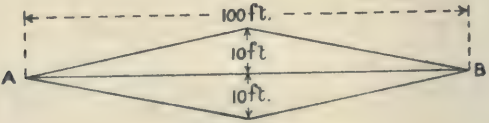


FIG. 89.

$$\begin{aligned} &\text{In above figure } r = 10 \text{ when } l = 50 \\ &\therefore 10 = c \times 50 \\ &\therefore \pm c = \tfrac{1}{5} \\ &\text{supporting force} = \frac{3{\cdot}1416}{70} \times \tfrac{1}{25} \times l^2 \pm \end{aligned}$$

Equation to curve of buoyancy $b = 0{\cdot}001795\ l^2$

At middle ordinate $b = 0{\cdot}001795 \times 50^2 = 4{\cdot}4875$ tons

Now, $b \times \dfrac{1}{0{\cdot}001795} (= p \text{ constant}) = l^2$ is the equation of a parabola with origin at the end of the middle ordinate and vertex at the origin.

Area of curve of weights for $\frac{1}{2}l = \dfrac{Wm \times l}{2}$

When Wm = middle ordinate curve of weights.

Area of curve of weights = area of curve of buoyancy.

$$\frac{Wm \times l}{2} = \tfrac{1}{3} \times 50 \times 4{\cdot}4875$$

$$Wm = \frac{50 \times 4{\cdot}4875}{3 \times 25}$$
$$= 2{\cdot}9916$$

The equation to the curve of weights is $W = kl.(k = 0{\cdot}059832)$.

The sheering force will be greatest at a water-borne section where $l = w$;

$$\text{or } 0{\cdot}001795l^2 = 0{\cdot}059832l$$
$$1795l^2 = 59832l$$
$$1795l^2 - 59832l + 0 = 0$$

$$\text{Resolving } l = \frac{(59832) \pm \sqrt{(59832)^2 - 4 \times 1795 \times 0}}{2 \times 1795}$$
$$= \frac{2 \times 59832}{2 \times 1795} \text{ or } 0$$

Therefore the water-borne sections are at A and B, or 33·33 feet from A and B.

Sheering force = area of curve of loads.

Area of curve of loads up to 33·33 feet from A

$$= \int_0^{33{\cdot}33} 0{\cdot}001795 \times l^2 - 0{\cdot}059832 \times l$$
$$= \frac{0{\cdot}001795 \times l^3}{3} - \frac{0{\cdot}059832 \times l^2}{2}$$
$$= 0{\cdot}000598 \times l^3 - 0{\cdot}029916 \times l^2$$
$$= 0{\cdot}000598 \times 37025{\cdot}9 - 0{\cdot}029916 \times 1110{\cdot}8$$
$$= 22{\cdot}141 - 33{\cdot}212$$

Reverse this as load is in excess.

$$\text{S.F.} = 11{\cdot}071 \text{ tons}$$

Neutral Axis of an actual Ship Section.—Take any trial, AB, four-tenths of the middle depth of the ship from the base line. Take the mean distance of the deck plating from the trial axis, and get the area of the plating. Take the shell plating, each plate separately. This will give you the M.I. above the trial axis. The same work is done for the M.I. *below* the trial axis.

Items.	Scant.	Area.	Levers.	Moments.	M.I.
Under-deck sheer strake .	$\frac{15}{20} \times 48$	36·0	y_0	$36{\cdot}0 \times y$	$36{\cdot}0 \times y^2$
„ plating . .	$\frac{7}{20} \times 96$	33·6	y_1	$33{\cdot}6 \times y_1$	$33{\cdot}6 \times y_1^2$
Middle-deck sheer plating	$\frac{12}{20} \times 48$	28·8	y_2	$28{\cdot}8 \times y_2$	$28{\cdot}8 \times y_2^2$
„ plating . .	$\frac{6}{20} \times 96$	28·8	y_3	$28{\cdot}8 \times y_3$	$28{\cdot}8 \times y_3^2$
Sheer strake	1×40	40·0	y_4	$40{\cdot}0 \times y_4$	$40{\cdot}0 \times y_4^2$
		ΣA		ΣAy	ΣAy^2

Before we can combine these calculations we have some practical considerations to take into account. When the ship tends to take the form in Fig. 90, such as when she is on the crest of a wave, she is said to **hog**. When in the hollow of a wave, as in Fig. 91, the tendency is to **sag**.

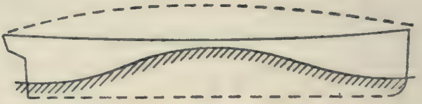


FIG. 90.

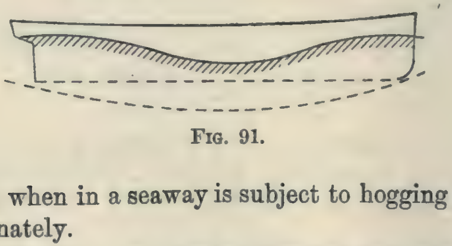


FIG. 91.

The ship when in a seaway is subject to hogging and sagging strains alternately.

Suppose Fig. 92 to be a strake of upper deck plating. If the ship is **hogging**, the plate is in **tension**. But as holes are punched in the plate, then only, say, seven-eighths of the section of the material is available for tensional strains.

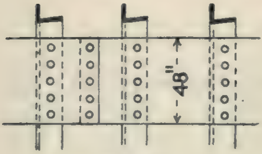


FIG. 92.

But if the ship is **sagging**, the whole of the material is useful, as the holes are completely filled up (the wood of the deck is also available for *compression*). Before, then, we can put the results which we have already obtained together, we must allow for tension and compression.

The object is to make the butts of the same strength at least as the "unavoidably weakest section," or section through the line of holes of beam rivets.

$I \propto BD^3$	B	D	Inertia for tension.	$\frac{I}{BD}$	$\frac{I}{BD^2}$	$\frac{I}{BD^3}$
All these are for actual ships.	30	23	59,000	85·5	3·71	0·161
	44	32	214,000	151·9	4·75	0·148
	57	40	613,000	268·8	6·72	0·113
	63	42	786,000	231·6	5·51	0·131
	44	32	190,000	135·7	4·22	0·131

By the above table we see that the ratio $\frac{I}{BD^3}$ is more nearly constant than the ratios $\frac{I}{BD}$ or $\frac{I}{BD^2}$

The M.I. for tension is arrived at by allowing one-seventh to one-eighth of the effective sectional area for the rivet holes.

Wood planking has about one-tenth the elasticity of steel. If there are three passing strakes to one stopping strake (Fig. 93), the tensional strength is reduced by one-fourth. Also, about one-thirteenth of each running strake is lost for bolt holes. Therefore the multiplier of wood planking area for tension is one twenty-fifth, and for compression (where the butts and bolts take up their full work) it is one-sixteenth.

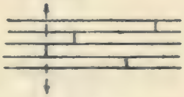


FIG. 93.

METHOD OF CALCULATING STRENGTH OF SHIP IN HOLLOW OR ON CREST OF A WAVE.

1. Draw in the **curve** of **buoyancy**. Calculate the areas of the sections up to the load water-line, and set up these as displacements for one foot of length.

2. Draw in the **curve** of **weights**. Take hull for 1 foot long and set up ordinate = weight thus found. Now add as a rectangle to this curve the weights of machinery, coal, winches, cable, etc.

Any reading of this curve should represent the weight of 1 foot of the ship's length at that point. The area of this curve should = area of curve of buoyancy, and their C.G. (longitudinal) be similar.

3. Draw in the **curve of loads.** This represents the difference between the buoyancy and the weight at any ordinate. If buoyancy is greater than weight, set reading above line, and *vice versâ.* Area above line should equal area below.

4. Draw in the **curve of sheering stresses.** This is found by taking the area of the curve of loads up to any point and setting the ordinate off to scale equal to this area.

5. Draw in the **curve of bending moments.** This is got by setting off to scale at any point the area of the curve of sheering stresses up to that point and setting the ordinate off to scale equal to this area. It is got in a similar way as the curve of sheering stresses from the curve of loads.

The maximum stresses a ship is subjected to take place when she is on the crest or in the hollow of a wave. And the higher the wave the greater the stress.

Height of a wave is about $\frac{1}{15}$ to $\frac{1}{20}$ of its length.

A wave 400 feet long is taken as 25 feet high.
„ 300 „ „ „ 20 „
„ 400 „ takes 9 secs. to travel its own length.
„ 300 „ „ 8 „ „ „

The C.B. must be in the same longitudinal position among waves as it is in still water, so that the wave curve must be humoured until this is so.

Maximum hogging moment, $D \times \frac{1}{35}$ length
„ **sagging** „ $D \times \frac{1}{50}$ „

Neutral Axis.—Assume an axis.

Take effective **sectional area** of all material above and below this axis. Multiply by distance of each particle from axis giving **moments.** Divide **moments** (sum of) by sum of **sectional areas** or difference of sums of moments by sums of areas, and set off axis above or below as necessary. Take section through water-tight frame. Deduct one-sixth of total sectional area where work is water-tight and one-eighth where not water-tight.

For wood decks take five forty-eighths of the sectional area, as this about represents its value in conjunction with iron.

Strength of Beams.—A beam is the arm of a couple or a series of couples as near as possible, because in almost all cases there are loads to be borne acting in practically vertical downward lines, and there are supports acting upwards almost vertically. Take a beam supported at ends and weighted between the extremities.

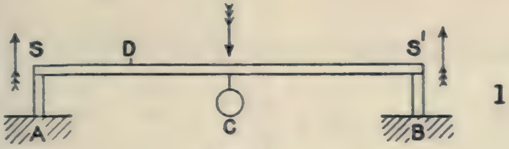


FIG. 94.

I. $$W = S + S_1$$

$$S = W \times \frac{CB}{AB} \text{ is got from } S \times AB = W \times CB$$

$$S_1 = W \times \frac{CA}{AB} \quad \text{,,} \quad \text{,,} \quad S_1 \times AB = W \times CA$$

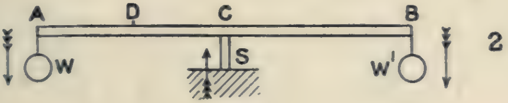


FIG. 95.

II. $$W = S - W_1$$

$$S \times BC = W \times AB \qquad \therefore S = W \times \frac{AB}{BC}$$

$$W \times AC = W_1 \times BC \qquad \therefore W = W_1 \times \frac{BC}{AC} \text{ or } W_1 = W \times \frac{AC}{BC}$$

In I.—

Sheering stress at any cross-sect. of AB betw. A & C $= S$
Bending moment ,, ,, ,, ,, (D) $= S \times AD$
Sheering stress ,, ,, ,, C and B $= S_1$

In II.—

Sheering stress at any cross-sect. of AB betw. A and C $= W$
Bending moment ,, ,, ,, ,, (D) $= W \times AD$
Sheering stress ,, ,, ,, C & B $= W_1$

Maximum bending moment in I. $= S \times AC$ or $S_1 \times BC$
II. $= W \times AC$ or $W_1 \times BC$

Sheering Stresses in Beams.—

Total load on beam $= W_1 + W_2 + W_3 + W_4 + W_5 + W_6$
$= \text{say } Wx$

This Wx will act through some part of the beam, say O, which will be distant from A, so that

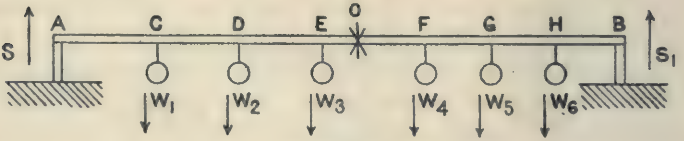


Fig. 96.

$$Wx \times AO = W_1 \times AC + W_2 \times AD + W_3 \times AE + W_4 \times AF + W_5 \times AG + W_6 \times AH$$

$\therefore AO =$ all above divided by Wx

This equation will give the point O
We can now get values for S and S_1

$$S \times AB = Wx \times OB \qquad \therefore S = W^1x \times \frac{OB}{AB}$$

$$S_1 \times AB = Wx \times OA \qquad \therefore S_1 = Wx \times \frac{OA}{AB}$$

Having got S and S_1, we can now determine the sheering stress at any part of the beam.

Sheering stress at any part betw. A and C = S
" " " C and D = $S - (W_1)$
" " " D and E = $S - (W_1 + W_2)$
" " " E and F = $S - (W_1 + W_2 + W_3)$

There will come a point where the magnitude of the sum of the loads equals the S. (supporting power). At this the sheering stress will be zero, and after it negative. This point is O.

Bending Moment in Beams.—Besides the sheering action there is also a tendency for the load to bend the beam so that it assumes a convex form on the side towards which the direction of the load acts.

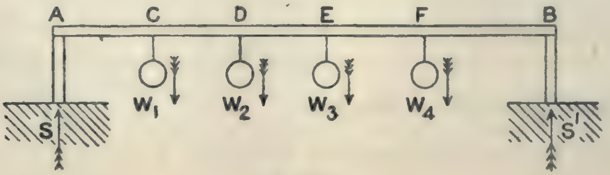


Fig. 97.

The bending moment at any section of the above is equal to the sum of the multiples of each sheering stress by the length of the division in which it acts.

Thus bending moment at—

$$C = S \times AC$$
$$D = S \times AC + (S - W_1) \times CD$$
$$E = S \times AC + (S - W_1) \times CD + \{S - (W_1 + W_2)\} \times DE$$

and so on

In Fig. 96, at the point O, where the sheering stress is zero, it will be found that the bending moment is at a maximum.

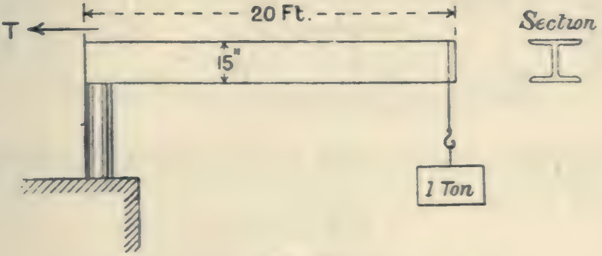


Fig. 98.

The sheering stress is of course = 1 ton, and the maximum bending moment—

$$= 1 \text{ ton} \times 20 \text{ feet} = 1 \times 240 \text{ inches}$$
$$= 240 \text{ inch-tons}$$

But there is a force, T, acting at the supporting column, and if the beam has to bear the stress of 1 ton at its other extremity, the moment of the force of T must be equal to the moment of the force of the weight (see foot of page 120).

The moment of the force T is T × its depth, or T × 15.

$$\therefore T \times 15 = 240 \text{ inch-tons}$$
$$\therefore T = \tfrac{240}{15} = 16 \text{ inch-tons}$$

But the tensile working stress was to be 4 tons; therefore the top flange of the section must be $\frac{16}{4}$ square inches = 4 square inches in area.

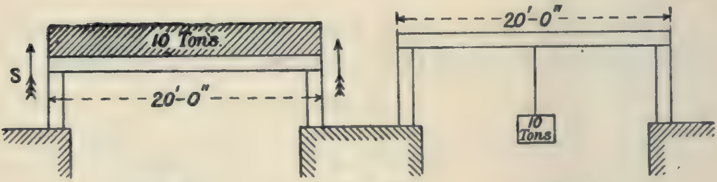
As the compressive stress is only half of the tensile, the lower flange must be twice the upper or = 8 square inches.

The vertical web need only be strong enough for a sheering stress of 1 ton.

CASES OF A BEAM LOADED AND SUPPORTED AT BOTH ENDS.

I.

The sheering stress in this case will be 5 tons. The moment will be greatest where weight is hung, viz. at centre, and will be equal to—



Case II. FIG. 99. *Case I.*

$$5 \text{ (S.S.)} \times 10 \text{ feet}$$
$$\text{or } 5 \times 120 \text{ inches} = 600 \text{ inch-tons}$$

II.

$$\left.\begin{array}{l}\text{Intensity of load in tons per} \\ \quad\text{inch at any part}\end{array}\right\} = \frac{10 \text{ (tons)}}{240 \text{ (inches)}} = \tfrac{1}{24} \text{ ton}$$

$$\left.\begin{array}{l}\text{at the supports the sheering} \\ \quad\text{stress would}\end{array}\right\} = \text{support} = \tfrac{1}{24} \times 10 \text{ feet}$$
$$= \tfrac{1}{24} \times 120 = 5$$

because the sheering stress at any point is the force S at either extremity minus the sum of the loads between that point and the extremity.

E.g. sheering stress at middle = S − (sum of the load up to middle of beam)

$$= \text{S} - 5 \text{ tons}$$
$$\text{But S} = 5 \text{ tons}$$
$$\therefore \text{ sheering stress at middle} = 0$$

The bending moment = the sum of the sheering stress multiplied by its distance from extremity.

The greatest bending moment will be found at the middle of the beam. But it will only be half of what it was in case I., because the sheering stress in I. is a rectangle, and in II. a triangle.

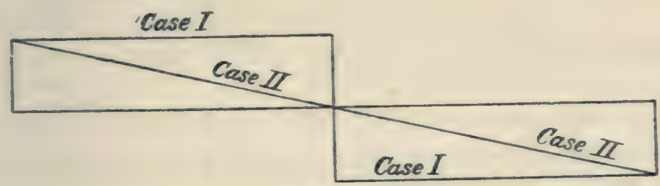


FIG. 100.

Therefore in II. the sum of the sheering stresses = half of the sum in I.,

$$\therefore \text{bending moment in II.} = \text{half bending moment in I.}$$
$$= 300 \text{ inch-tons.}$$

Moment of Inertia.—

$$\frac{P}{Y} = \frac{M}{I}$$

will give us the intensity of the stress on any part if we know the value of I., or the moment of inertia, of the section about the neutral axis.

Unit of area is 1 square inch. Distances are in feet.

Example.—A horizontal plate. In the section (such as a deck plate)—

$$\text{Moment of inertia} = \text{sectional area} \times (\text{distance from NA})^2$$

Example.—A vertical plate. In the section (such as side plating)—

$$\text{Moment of inertia} = \text{sectional area} \times (\text{distance from its C.G. to NA})^2 + \tfrac{1}{12} \text{ of the area} \times \text{square of its breadth}$$

Do this for all the plates above or below, and the sum of these results will be the moment of inertia of the section.

Knowing this, the only unknown quantity in the above equation is P, which we want to find.

Example.—A vessel on the crest of a wave is subjected to a hogging strain of 50,000 foot-tons. The moment of inertia of effective section about NA = 150,000. Find tension in tons per square inch on upper deck plating, which is 18 feet above NA.

$$\frac{P}{y} = \frac{M}{I} \qquad \therefore P = \frac{My}{I} = \frac{50000 \times 18}{150000} = 6 \text{ tons}$$

Elementary moment of inertia

$$= \tfrac{1}{12}by^3$$

Now, considering both sides of a ship, y becomes $2y$, and the new inertia

$$= \tfrac{1}{12}b(2y^3) = b\left(\frac{8y^3}{12}\right) = \tfrac{2}{3}by^3$$

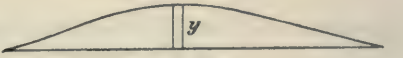


FIG. 101.

If b is small enough, say the breadth of a line, it may be ignored, then the equation becomes

$$I = \tfrac{2}{3}\Sigma y^3$$

That is, two-thirds area of a curve of ordinates cubed.

1	$y1$	$y1^3$	1	$f1$
2	$y2$	$y2^3$	4	$f2$
3	$y3$	$y3^3$	2	$f3$
4	$y4$	$y4^3$	4	$f4$
5	$y5$	$y5^3$	1	$f5$
				$\underline{x}$

h = interval $$\frac{x \times 2 \times h}{3 \times 3 \times 35} = \text{M.I.}$$

RIVETS AND RIVETED JOINTS.

At a joint the resistance of the rivets to sheering and the plate to breaking should be equal.

The strength of the whole is the strength of the weakest part.

Any excess of strength of one over the other is useless.

A riveted joint can never be as strong as a continuous plate.

But a riveted joint can be at least as strong as a section through the plate at *its* weakest part; *e.g.* at the frames, beams, etc.

Any stronger connection is unnecessary.

So we must first know the resistance of iron and steel to extension or compression, and of a rivet to sheering.

Tensile strength of B.B. iron, 22 tons per square inch with the grain.

Tensile strength of B.B. iron, 18 tons per square inch against the grain.

Wrought-iron offers about four-fifths resistance to compression that it does to extension.

Resistance of rivets to sheering = tensile strength of iron of same quality.

E.g. sheering strength of $\frac{3}{4}$ rivet = 10 tons, or $22\frac{1}{2}$ tons per square inch.

But 22 tons per square inch iron reduces to about 18 tons per square inch in vicinity of rivet-holes by the punching. Diameter of rivets is fixed by Lloyd's.

If rivet-holes are rimed or annealed, there is practically no loss in tensile strength.

RELATION OF DIAMETER OF RIVET TO THICKNESS OF PLATES.

Steel.—Tensile strength of plate through A = $2d \times t \times 24$ (tensile).

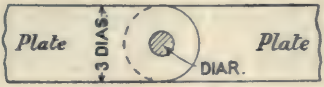


FIG. 102.

Sheering resistance of rivet through A = $d^2 \times 0{\cdot}7854 \times 27$ (tensile). But rivet should be on the point of sheering when plate is on the point of bursting.

$$\begin{aligned} \therefore 2dt \times 24 \text{ should } &= d^2 \times 27 \times 0{\cdot}7854 \\ 48dt \quad \text{,,} \quad &= 21d^2 \\ 2\tfrac{1}{3}t \quad \text{,,} \quad &= d \end{aligned}$$

i.e. the diameter of rivet should never exceed $2\frac{1}{3}$ times the thickness of plate.

Iron.—

$$2dt \times 18 = 17{\cdot}3d^2$$
$$36dt = 17{\cdot}3d^2$$
$$2t = d$$

i.e. the diameter of rivet should never exceed twice the thickness of plate.

QUESTIONS ON CHAPTER VII.

Ques. What is the ultimate sheering and tensile strengths of steel rivets and plates respectively? Find the breaking strength of a single butt double chain riveted to a plate 30 inches wide and $\frac{1}{2}$ inch thick, connected with $\frac{7}{8}$-inch rivets spaced 3 inches apart. Find the force necessary to break the plate across a frame line where the rivets are spaced 6 inches apart.

Ans. Sheering strengths of steel rivets in steel plates—

$\frac{3}{4}$-inch rivets = 11·5 tons
$\frac{7}{8}$-inch „ = 15·25 „
1-inch „ = 20·25 „

Tensile strength of unpunched steel plates are as follows:—

To Lloyd's tests 28–32 tons per square inch of section
To Admiralty „ 26–30 „ „ „

$$\text{Number of rivets in butts} = 10 \times \tfrac{2}{1} = 20$$
$$\therefore \text{sheering strength} = 20 \times 15{\cdot}25 = 305 \text{ tons}$$

Breaking strength through a row of rivets

$$= \tfrac{1}{2}\left[30 - (10 \times \tfrac{7}{8})\right] \times 24 = (15 - 4\tfrac{3}{8}) \times 24 = 10\tfrac{5}{8} \times 24 = 255 \text{ tons}$$
$$\therefore \text{breaking strength of butt} = 255 \text{ „}$$

Breaking strength through a line of frame-holes

$$= \tfrac{1}{2}(30 - 5 \times \tfrac{7}{8}) \times 26 = \tfrac{1}{2}(30 - 4\tfrac{3}{8}) \times 26 = 333\tfrac{1}{8} \text{ tons}$$

Ques. The punching of mild steel plates reduces the ultimate tensile strength of the material between the holes. State the amount of this reduction; also describe the methods of forming holes or treatment of plate by which the loss of strength is avoided in plating intended for important structural parts of a vessel.

Ans. When mild steel plates are punched with holes spaced about seven to eight diameters apart, then the ultimate tensile strength of the material between the holes is reduced from 28 tons per square inch of section to 24 tons per square inch of section. If a plate were punched with holes spaced from three to four diameters apart, then the ultimate tensile strength of the material between the holes would be about 22 tons per square inch of section.

$$\text{First reduction about } \tfrac{4}{28} \times \tfrac{100}{1} = 14{\cdot}28 \text{ per cent.}$$
$$\text{second „ „ } \tfrac{6}{28} \times \tfrac{100}{1} = 42{\cdot}42 \text{ „}$$

When the plates are riveted up, the ultimate tensile strength between the holes is increased about 1 ton per square inch in the first case, and about 2 tons in the second.

There are three methods by which the loss of strength of steel plates due to punching can be avoided, viz. by drilling the holes, punching the holes smaller and then countersinking, and by annealing.

The first is an expensive method, and never adopted where it can be avoided. In the second method, after the holes have been punched small, the plate is taken to a table and laid there. A crane with a horizontal post jib is fixed so that the jib has a sweep which covers any part of the table. A vertical rod, with a point which is made to rotate by a system of cog-wheels driven by a belt, is suspended from the jib end. A man is in attendance, and, when he has the point of the rod over a hole, by pressing a lever he inserts the point in the rivet-hole. He keeps it there for a short time, the end rotating all the while, and when he eases the lever out of the hole then it is countersunk. Water is run down to the end of the rod by means of a small pipe, and this serves to keep that part of the plate cool which the end of the countersink comes in contact with.

To anneal a plate, it is placed in a furnace and heated to a red heat. The furnace is then allowed to die out very gradually, and it has been found that this restores the strength lost through punching the plate. The British Admiralty require all butt straps for important structural parts of a vessel to be annealed, and Lloyd's require all straps above $\frac{10}{20}$ inch to be countersunk. They also require the shell plates to be countersunk and flush riveted on the outside.

Ques. Draw out an arrangement of bottom plating amidships extending four strakes outward from flat-plate keel, and show the edges of butts with an example of the riveting of each, taking your own scantlings and sizes of rivets; and compare the tensile strength of a section through a row of rivet-holes with that at a butt.

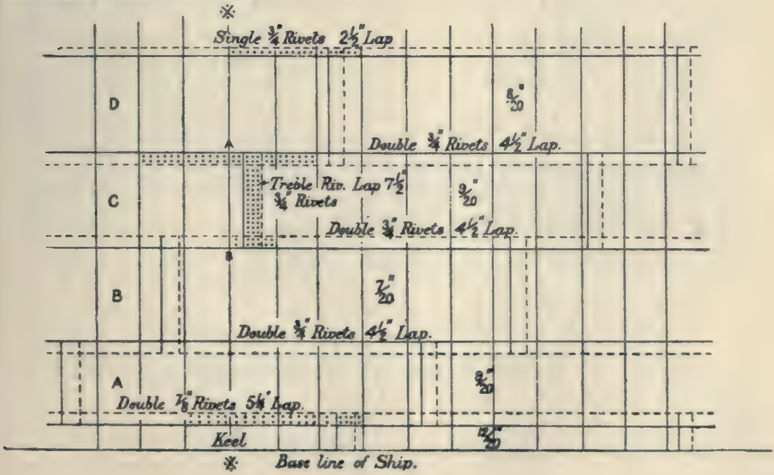


FIG. 103.

Ans. Comparative tensile strengths taken through line of frame-holes ** and through butt lap in C strake, and through a line of frame-holes without encountering a butt.

The difference is only at the line AB in C strake.

Tensile strength through frame line AB (see * * Fig. 103)

$$= [46 - (9 \times \tfrac{3}{4})] \times \tfrac{9}{20} \times 26 \text{ tons}$$
$$= \tfrac{157}{4} \times \tfrac{9}{20} \times \tfrac{26}{1} = \tfrac{18369}{40} = 459{\cdot}22 \text{ tons}$$

Tensile strength through butt, sheering rivets in seams and back to frame line.

$$= \{(10 \times 11{\cdot}5) + [46 - (17 \times \tfrac{3}{4})] \times \tfrac{9}{20}\} \times 24$$
$$= 115{\cdot}0 + \left(\frac{133 \times 9 \times 24}{4 \times 20 \times 1}\right)$$
$$= 474{\cdot}1 \text{ tons}$$

Therefore the tensile strength through a frame line of rivets is less than the tensile strength through a butt by (474·1 − 459·22) = 14·88 tons

Ques. A steel stringer plate is 48 inches wide and $\frac{7}{16}$ inch thick. Sketch the fastenings at a butt and at a beam, and show by calculation that the connection is a good one.

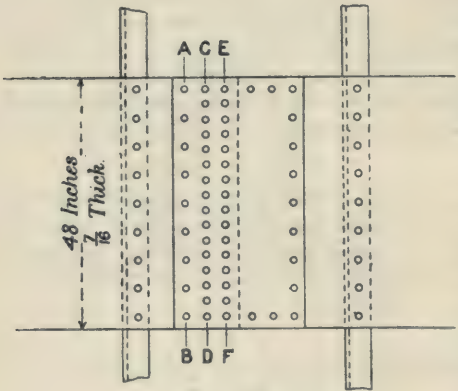


FIG. 104.

Ans. There are five ways in which the connection of the two plates could be broken. (1) By all the rivets on one side of the butt sheering; (2) by the plate breaking through the line of rivet-holes AB; (3) by the strap breaking through the line of holes EF; (4) by the plate breaking through CD and sheering the rivets through AB; (5) by the strap breaking through CD, and sheering the rivets through EF.

Tensile strength through the unavoidably weakest section of the plate at any point, viz. through a line of beam-holes

$$= \left(48 - \frac{9 \times 3}{4}\right) \times \tfrac{7}{16} \times 26$$
$$= 470 \text{ tons}$$

Therefore the strength through any of the breaking sections must be equal to 470 tons.

(1) $$\frac{470}{11{\cdot}5} = 41 \text{ rivets on each side of butt}$$

(2) As the rivets through AB are the same spacing as through a line of beam-holes, therefore there is the same tensile strength.

(3) Strength of strap through EF—

$$=\left(48 - \frac{16 \times 3}{4}\right) \times \tfrac{9}{16} \times \tfrac{24}{1} = 486 \text{ tons}$$

(4) Strength of plate through CD—

$$=\left(48 - \frac{16 \times 3}{4}\right) \times \tfrac{7}{16} \times \tfrac{24}{1} = 378 \text{ tons}$$

plus sheering strength of rivets through AB

$$\begin{aligned} = 9 \times 11{\cdot}5 = {} & 103{\cdot}5 \text{ tons} \\ & \underline{378 \quad ,,} \\ & 481{\cdot}5 \quad ,, \end{aligned}$$

(5) In this case, in addition to the plate breaking through CD, the rivets through EF have to be sheered, and as the tensile strength through a line of holes, EF, the same spacing as CD has been proved above the standard strength, it therefore follows that more strength is required to break the connection in this case.

It has thus been proved that through all the sections at which the connection is likely to give way the strength is above the standard.

Therefore the connection is a good one.

Ques. A wrought-iron anchor weighing 60 cwts. is suspended in salt water by a chain: find the pull on the chain in pounds.

Ans. Weight of anchor in lbs. = 60 × 112 = 6720 lbs.

1 cubic foot of wrought iron = 480 lbs.

1 cubic foot displacement by anchor = 6720 ÷ 420 = 14

1 cubic foot of water = 64 lbs.

∴ 64 × 14 = 896 = weight of water displaced in lbs.

∴ tension on chain = 6720 − 896 = 5824 lbs.

Ques. Describe hogging and sagging strains, and state under what conditions each is experienced.

Ans. **Hogging Strain.**—When a ship is on the crest of a wave, there is an excess of weight at the ends and an excess of buoyancy amidships. The ship may be roughly compared with a beam supported at the middle, with weights at the end. The consequence is that there is a tendency for the ends to droop. This is termed hogging.

Sagging Strain.—When a ship is in the hollow of a wave, there is an excess of weight amidships and an excess of buoyancy at the ends. The ship may be roughly compared with a beam supported at the ends and loaded in the middle. The consequence is that there is a tendency for the middle to droop. This is termed sagging.

Hogging strain is the most important, and even when the vessel is in still water there is a tendency to hogging.

In hogging, the upper portions of a vessel are in tension and the lower parts are in compression.

In sagging, the upper portions of a vessel are in compression and the lower portions are in tension. The portions of a ship's structure resisting these strains are upper and main decks, stringers, sheer strakes and plating, below and at bilge, both of inner and outer bottom, keel, keelsons, and any longitudinal framing.

These strains would be termed structure strains.

Ques. What is meant by (1) local strength; (2) structural strength? Point out in what way pillars to beams may be regarded as increasing the structural strength of steel ships.

Ans. **Local strength** is the strength that is required to resist local strains. As these strains are very numerous, it will be sufficient to give attention to only a few of them for illustration. In some parts of the vessel there may be heavy loads over a short distance, such as machinery, etc., which would be considerably in excess of the upward force of buoyancy, and thus tending to strain the ship for a certain distance. Then again there is a considerable strain due to the propeller working, which not only tends to strain the vessel as a whole, but also strains her locally, as, *e.g.*, the thrust upon the thrust-bearers and the plating in way of the stern frame, etc. The thrust of a mast would tend to force the ship out at the bottom, and numerous other cases could be stated where the vessel suffers local strains by heavy weights, etc., and these strains have to be provided for by fitting, say, longitudinal girders under the engines, etc., and elsewhere increasing the thickness of plates and beams where required to meet these local strains.

Structural strength is the strength that is required to meet the strains that are put upon the ship as a whole. The two principal strains that are put upon a ship as a whole are longitudinal and transverse strains. The longitudinal strains are the more important of the two, and the most attention is generally given to this class of strain, viz. hogging and sagging. The skin of the vessel, longitudinals, double bottom, stringers, deck plating, side keelsons, and all parts running longitudinally, if properly connected together, lend to the structural strength of the ship to resist longitudinal bending stresses, together with the frames, beams, etc.; but the frames, beams, floor plates and pillars give the most resistance to transverse strains.

The beams together with the pillars are fitted to support the deck and its loads, but they perform another important duty, that is, the beams tie the frames together, forming a continuous girder which tends to resist the changing of the form of the transverse section. When a ship is floating upright there is a pressure of buoyancy pressing equally at all sides, and this, together with the heavy weights on deck, tend to change the transverse form of the ship, and when the vessel is rolling there are still more severe strains experienced, stresses tending to force the bilges in and thus again change the transverse form; but if the pillars are securely fastened at the head and keel, they not only act as supports for the deck and its weight, but they tend to assist in resisting compressive and tensile stresses due to rolling as stated above.

Ques. What are panting strains? and by what means may they be resisted?

Ans. Panting strains take place at the fore end of a ship. The term is used to describe the working in and out of the sides of a vessel, and is usually found where the sides of the vessel are comparatively flat, say at the fore and after end, but fore end especially.

To prevent panting, fit panting stringers about 30 feet in length, also extra strong beams, connected by a stringer, not more than 4 feet apart and composed of bulb plates and two angles; also breasthooks.

In full ships below the water-line it is found that when seas strike vessels, if they are not specially strengthened, the sides give out, and to further prevent this strain Lloyd's require that the midship thickness of plating on two strakes should be carried right forward instead of reduced at the three-fifths length as is usual.

Ques. Two inside strakes of shell plating are each $52 \times \frac{9}{20}$, and one outside strake $44 \times \frac{9}{20}$, steel rivets, double riveted, butt strap and double-riveted seams. Calculate the different possible modes of fracture of the three plates with butt on outside strake.

Ans. (1) Plates may break (A, B, and C) through holes A, B.

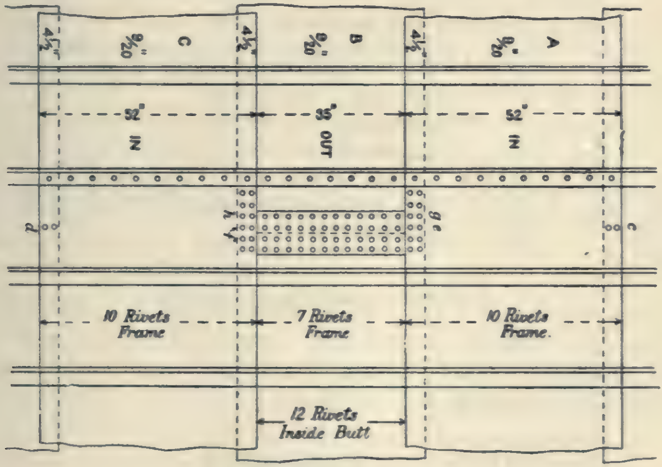


FIG. 105.

ABC = 52 inches + 44 inches + 52 inches = 148 inches unpunched plating
less rivet-holes $27 \times \frac{3}{4} = 20\frac{1}{4}$ inches
nett plating $= 127\frac{3}{4}$ „
tensile strength $= 127\frac{3}{4} \times \frac{9}{20} \times \frac{26}{1} = \frac{59787}{40}$
= 1494 tons

(2) Plates A and C through *c*, *e*, *f*, *d*, and strap B through *e*, *f*.

A and C = 52 inches + 52 inches = 104 inches unpunched plating
less rivet-holes $8 \times \frac{3}{4} = 6$ inches
area effective = 98 „

tensile strength = $\frac{98}{1} \times \frac{9}{20} \times 27\frac{1}{2} = \frac{24255}{20}$
= 1213 tons
strength of butt through *e*, *f* to be added = 345 „
total strength = 1558 „

(3) Break plates A and C through holes C, D, and sheer all rivets on one side of butt.

A + C = 1213 tons
+ 24 rivets × $11\frac{1}{2}$ = 276 „
1489 „

(4) Plates A, B, C break though line of holes *c*, *g*, *h*, *d*.

A + C = 1213 tons
B = 44 − 16 holes × $\frac{3}{4} = \frac{32}{1} \times \frac{91}{20} \times \frac{24}{1}$
= 345 + 1213
= 1558 tons

(5) Plates A and C through holes A, B, and sheer edge rivets between A, B and *g*, *h*, and break plate B through *g*, *h*.

A and C = 52 inches + 52 inches = 104 inches
− 20 holes at $\frac{3}{4}$(15 inches) = 89 „
tensile strength = $\frac{89}{1} \times \frac{9}{20} \times \frac{26}{1} = \frac{10413}{10}$
= 1041 tons
+ 17 rivets × $11\frac{1}{2}$ = 195 „
+ B through *g*, *h* = 312 „
1548 „

(6) Plates A and C through line of frame-holes A, B, and sheer all edge rivets and butt rivets on one side of butt.

A and C = 1041 tons
+ 40 rivets to sheer × $11\frac{1}{2}$ = 460 „
1501 „

(7) Break plates A and C through holes A, B, and sheer all edge rivets on one side of butt and break strap through *e*, *f*.

A and C = 1041 tons
+ all edge rivets on one side of butt, 16 × $11\frac{1}{2}$ = 184 „
+ strap through *e*, *f* = 345 „
= 1570 „

CHAPTER VIII.

TONNAGE—FREEBOARD—CORROSION AND FOULING.

Tonnage.—There are several methods of measuring tonnage, *e.g.* the British, Suez Canal, Italian, Danube rule, etc. The two most important are the British and Suez.

In British early mercantile days the greatest shipping trade was in carrying wine from France to this country. This wine came in casks called "tuns," which were nearly all the same size. The vessels employed in the trade were of different sizes, and a handy way to understand the various sizes was to say they could carry so many tuns of wine. This method became universal, and although a vessel was not engaged in the wine trade, yet owners, knowing the size of the wine tun, had a knowledge also of the capacity of the boat under notice for other trades. The tun, then, of 100 cubic feet is the British system of measuring a vessel's capacity. The word "tunnage" has now been corrupted to "tonnage," and it is very hard to disassociate tonnage with ton weight. For a vessel to have, say a tonnage of 5000, means that the internal capacity of that ship is 5000 × 100 cubic feet, and does not represent the weight of the vessel nor the weight of her cargo.

To measure Tonnage.—Divide the ship into twelve equal parts, if over 225 feet in length; under this length the number of ordinates is reduced. The length is measured from where the line of the inside of frames cuts the centre line at the bow and stern on the upper deck; the breadth is taken inside the cargo battens or spars; the depth is taken from the top of 2½-inch ceiling to the top of the upper deck beams, deducting one-third of the camber. This depth is divided into six equal parts when the vessel is 16 feet or over in depth; under this depth the number of ordinates is reduced. Measuring the breadths and putting them through Simpson's rules gives the area. Combining these areas by Simpson's rules we get the cubical contents. Dividing this by 100 gives the vessel's tonnage. This is called the *under-deck tonnage.* To it has to be added all the closed-in spaces above the upper deck. The meaning of the term "closed-in spaces" is very elastic, and it is often possible to evade the measurement of the space by some simple device, such as enclosing an entire bridge except an opening about 3 feet wide. This bridge is, then, not a closed-in space, and consequently not measured in tonnage.

A closed-in space is a space in which the cargo, stores, or passengers may be carried.

Some such spaces are exempt, viz. wheelhouse, galley, w.c.'s, etc. When all other closed-in spaces have been added, the result is the *gross tonnage.*

The engine room and boiler room have been already added in the under-deck tonnage. These spaces are earning no money for the owners, but are wholly employed in propelling the steamer. The Board of Trade allow a certain amount to be deducted from the gross tonnage because of this.

The engine and boiler rooms and tunnel are measured. If these are 13 per cent. of the gross tonnage, a deduction of 32 per cent. is allowed. Thus, a vessel's gross tonnage is 10,000. The machinery space measures 1300 tons. The deduction is, therefore, 3200 tons from the gross. Where the machinery spaces do not measure 13 per cent., then $1\frac{3}{4}$ times what they do measure is deducted. Where they are greatly in excess of 13 per cent., it is better to get $1\frac{3}{4}$ times the actual amount off than 32 per cent. of the gross.

Paddle steamers have different deductions to the above, which are for screw steamers.

Other spaces than the machinery spaces are also deducted, viz. crew space, boatswain's stores, captain's cabin, chart room, and donkey-boiler room. When all these spaces have been deducted from the gross tonnage, the result is the *nett register tonnage.*

Suez tonnage is very similar to British measurements, and it would be out of place here to go into the small differences between the two systems.

The following comparison of the two systems of measurement for the same vessel will be interesting:—

	British.	Suez.
Under-deck tonnage	3167	3085
Gross tonnage	3428	3363
Deductions (*ex* machinery)	130	110
	3298	3253
Machinery spaces (1¾)	718	627
Nett register	2580	2626

If peaks forward and aft containing water ballast are not to be included in under-deck tonnage, the peaks must not be more than 1 foot above the load water-line.

Freeboard.—Freeboard depends on the class of vessel and the form. A ship built to Lloyd's three-deck class is stronger than one built to the shelter or awning class, and it is consequently allowed to load deeper. The freeboard is the height of upper deck above the water at the greatest permissible draught.

Freeboard tables are arranged for—

"A," flush-deck vessels of Lloyd's highest class.

"B," spar-deck vessels.

"C," awning-deck vessels.

"D," sailing vessels.

Intermediate classes have their freeboard determined by interpolation.

Vessels of the same class and to the same dimensions will carry, on the same draught of water, more or less cargo, according to their form. A very full ship can carry more than a very fine ship. Each class, then, is graduated according to the form of the vessel. Thus in class "A" a vessel of, say, 550 feet in length and coefficient of fineness of 0·68 would be allowed to load 12 inches deeper than the same ship if her coefficient of fineness was 0·82.

Table "A" in freeboard tables is for flush-deck vessels of highest class scantlings. If a three-deck vessel has a poop, bridge, and forecastle built on top of the flush deck, she is obviously a better boat than without these.

An awning-deck boat has complete erections. The freeboard of the poop, bridge, and forecastle boat is obtained by taking a mean between the flush decker and the awning decker. The exact amount is determined in proportion to the percentage of erections.

A shelter-deck vessel is assumed as a flush decker, and the maximum allowance for erections is deducted. Awning-deck vessel has the freeboard calculated below the main deck.

A vessel intermediate between, say, awning and spar deck class is taken as an awning decker. The midship scantlings are compared, and a reduction to the freeboard in proportion to the excess scantlings over an awning decker is allowed. Three-fifths of the difference between awning and spar deck class is permitted for longitudinal strength—that is, if a vessel is spar-deck class in her shell plating, decks, etc., three-fifths of the difference between the two classes is deducted from the awning-deck class. Two-fifths of the difference is allowed for items of transverse strength.

A spar-deck vessel may have her freeboard calculated as a three-decker, and a reduction of 7½ inches draught will generally cover for the reduced scantling. If a vessel is between two types, always take to the lowest type and compare scantlings.

Corrosion and Fouling.—"Corrosion" means the actual wearing away of the plating or material by pitting or scaling. "Fouling" means the adhesion of small animal or vegetable life to the surface of the material and the growth thereon. The ocean may be assumed to be a vast acid bath and seething with life. When plates are exposed to the action of the sea, they immediately begin to get eaten away as in a galvanic cell. As long as this eating away continues, the small animals and vegetables in the water cannot get a hold on the plate to grow; but if the plate is covered with something to prevent its wearing away, they fasten on to the surface until, if they are not removed, the whole under-water body of the vessel is one mass of grass and barnacles, forming a serious hindrance to speed.

We seem here to be between two evils. If the metal is left bare it will wear away; if it is coated, then grass and barnacles grow on it. This, of course, applies only to the outside. In the inside of the ship there is no fouling, but corrosion is even more rapid, and from different causes, but chiefly because of the bilge water. And the corrosion will be greater if the acid bath (in this case the bilge water) is warm. This occurs more particularly under the engines and boilers, and plates are made thicker, or of iron, in these places. The drippings, again, from some cargoes, such as sugar and molasses, have a very rapid corroding effect on iron or steel. Other cargoes, such as coal or grain, have natural heat, and this acts on the surfaces very readily. All that is necessary to prevent internal corrosion is to cover the surfaces well with a good coat of red-lead paint and keep them covered. Every particle of steel or iron inside should be painted, and the paint renewed regularly. Parts inaccessible should be thickly coated with cement.

When plates are received from the makers they should have what is termed the "mill scale" removed. All new plates scale, and until they do scale they will not hold paint. The ordinary method of scaling plates is by rusting naturally by exposure to wind and weather, and then chipping them; or they may be dipped in a solution of weak hydrochloric acid and then washed with clean water, and sometimes a coating of hot linseed oil brushed over them. A single coat of paint is considered sufficient before launching, the final coats being put on when the vessel is in dry dock.

Various methods are employed to prevent fouling. In the Royal Navy many of the vessels are entirely sheathed under water and then coated with copper plates. The sheathing here is used for insulating the two metals, the steel of the hull and the copper covering. If those metals get in contact in salt water, a strong galvanic action sets in, and the steel is eaten away very rapidly. The copper plates gradually wear away in salt water. This gradual wearing away prevents the attachment of insects and vegetable life. But the copper eventually entirely wears out and must be renewed, thus entailing such expense as to make its use prohibitive in the merchant service. In merchant vessels galvanic action may be set up locally if certain precautions are not adopted. A copper pipe through the side of the ship would set up a very strong action if it is not insulated from the steel. Bronze propellers, again, must be protected. The usual way to do this is to have the inside of the stern-post covered with strips of zinc, which centralize the action and take all the pitting. When these are worn too much they can be easily renewed.

In the merchant service anti-fouling paints are used to keep the vessel's skin clean. These paints may be poisonous and kill any life that seeks to attach itself to the shell, or they may have the same action as copper, and by slowly washing away prevent any adhesion; or they may be a combination of the two. In certain trades and waters these compositions are very successful, but in other waters they are of very little use. In the great trading lines of ocean commerce, however, such as the North Atlantic, the Indian, and the Australian, they give splendid results, and as they can be easily renewed after every voyage, their retention in the mercantile service—at least, until the advent of some material vastly cheaper and lighter than copper and sheathing—seems assured.

QUESTIONS ON CHAPTER VIII.

(1) *Ques.* What is reserve buoyancy? (2) What importance do you attach to reserve buoyancy?

A vessel of constant triangular section floats in salt water with its apex downwards. Express its reserve buoyancy as a percentage of the total buoyant volume, and also as a percentage of its displacement when it floats at 16 feet. Diameter 280 feet × 44 feet moulded × 20 feet deep.

Ans. (1) **Reserve Buoyancy.**—It is the amount of buoyancy or floating power which is held in reserve to be drawn upon in the case of foundering when the ship is holed. It is all the buoyancy above the water-line which is not utilized. It is known either as a percentage of the total buoyant volume, or as a percentage of the *displacement* or utilized buoyancy.

(2) **What Importance do you attach to Reserve Buoyancy?**—(*a*) Buoyancy + reserve buoyancy = total floating power.

(*b*) It fixes the deck at a sufficient height above water to give the ship good range of stability.

(*c*) If a ship had *no* reserve buoyancy she would sink.

(*d*) Supposing the vessel to be holed, the reserve buoyancy would have to be drawn upon to keep her afloat, and as soon as she lost her reserve floating power she would sink.

(280 Feet Long.)

As a Percentage of Total Volume.

$$\text{Total buoyant volume} = \frac{44 \times 280 \times 20}{2}$$
$$= 123200 \text{ cub. ft.}$$
$$\text{utilized buoyancy} = \frac{280 \times 35{\cdot}2 \times 16}{2}$$
$$= 78848 \text{ cub. ft.}$$
$$\text{reserve buoyancy} = 123200 - 78848$$
$$= 44352 \text{ cub. ft.}$$

123200)788480(64
739200
492800
492800

100 − 64 = 36%

Percentage of reserve buoyancy to total buoyant volume = 36%

As a Percentage of Displacement.

Volume utilized = 78848 cub. ft.
reserve volume = 44352 „
percentage = $\frac{44352}{78848}$

78848)443520(56·25%
394240
492800
473088
197120
157696
394240

As a percentage of displacement = 56·25%

Ques. Describe how the mill scale formed on steel plates during manufacture can be removed. From what parts of the vessel is it especially necessary that this removal should be thorough, and why? If the propellers of the vessel were of manganese bronze, describe in detail the precautions necessary to prevent injury to the steel hull in the neighbourhood of the propellers.

Ans. Take the steel plate after it has been in the yard some time and, after brushing, bath it in dilute hydrochloric acid (1 part acid and 19 water) for a few minutes. Then give it a good scrubbing with steel wire brushes, and afterwards wash it with clean water. The plates most liable to corrosion are often left unpainted as long as possible before launching so as to weather. They are then thoroughly scraped and painted. The parts which should have especial care taken to remove the scale are the shell, deck, and the plates under the boilers, also the plates in the vicinity of the bilges and hold wells. The reasons are because the shell plates are nearly always in contact with the salt water, either being wholly submerged or being constantly splashed, and corrosion is more likely to take place in these parts. For the same reason should the deck plates be kept free from mill scale. The parts under the boilers are very liable to corrosion owing to galvanic action being set up by means of the drippings of oil, the gases formed by the heat, and the dirty water. It has been proved by experiment that dirty bilge water tends to set under way corrosion of material more readily even than sea-water. All the parts mentioned should therefore be thoroughly clear of mill scale, owing to the fact that corrosion takes place at a rapid rate when the scale is allowed to remain. At each side of the vessel, in the immediate vicinity of the blades of the propellers, strips of zinc about 2 feet long × 3 inches × ½ inch are secured to the shell plating because, owing to the galvanic action set up by the propellers in the sea-water, zinc will gradually wear out, and can then be renewed, thus saving the shell plates from the extra corrosion due to the presence of manganese propellers. A zinc collar is also fitted between propeller and stern-post or strut.

CHAPTER IX.

RUDDERS—STEERING GEAR—I.H.P.—PROPELLERS.

THERE are almost as many types of rudders as there are types of vessels. Even the highest authorities are at variance in respect to the best form of rudder. An eminent firm of shipbuilders designed a *broad and shallow* balanced rudder for a torpedo destroyer; but as it was not a success, other designs were tried, and the one ultimately adopted as giving the best results was very different from the original rudder, being both *narrow and deep*. In ordinary cargo vessels a good area of rudder is essential, and one fairly broad at the foot is the commonest form.

The rudder used in the Admiralty is of the balanced class. By "balanced" is meant a rudder hung approximately in the middle, so that in turning the action of the water helps to turn the rudder, and allows it to be turned with little resistance. The ordinary proportions are two-thirds area aft of the post and one-third area forward of the post. One disadvantage which this kind of rudder has is that it makes a greater drag in the water than the ordinary form. Instead of the water being guided along and off, it makes an abrupt stop and divides in two directions. This drag is very appreciable at high speeds, and raises the question whether the obvious advantages are greater than the disadvantages. Its advantages are ease in turning and greater manœuvring power for the vessel.

Other rudders fitted are the double rudder, the twin rudder, and the bow rudder. The bow rudder is fitted in some paddle steamers, in addition to the ordinary stern rudder, and is very useful in taking and leaving piers where the vessel has to go sternwards for some distance. A twin-screw vessel may be turned by the screws, or a paddle boat, where the paddles are independent, may be turned by the paddle. The jet rudder, where the turning power was derived from jets of water playing from the quarters, has been experimented upon.

Steering Gear.—The simplest form of steering gear is the hand tiller, and with this form there are three ways in which a breakdown may occur.

1. The tiller may break.
2. The rudder may break.
3. The tiller may be strong enough to resist all the strength exerted on it, and if this strength does not turn the rudder, the head is bound to break by twisting.

Nos. 1 and 2 can be considered at once, as each depends on the pressure of water on the rudder.

A tiller in turning a rudder must do two things. It must, first, move the rudder from rest to a certain position; and, secondly, it must hold it in that position. The pressure on a rudder at right angles to the ship's direction is found from the formula—

$$1{\cdot}12 \times \tfrac{11}{10} \text{ speed of ship} \times \text{area of rudder}$$

The correction for any angle of rudder is to multiply by the sine of the angle. This gives pressure on rudder in pounds, and to get the tons, divide by 2240. Speed is in feet per second; area in square feet.

The moment to be resisted in the rudder head is this pressure multiplied by its lever. The lever is the distance from the C.G. of the rudder to the centre of the rudder stock. The C.G. is really not what is wanted, but a little forward of it, and called the centre of effort. The distance between the two points is so small that for the pressure the longitudinal C.G. of the immersed area may be taken. Power to be resisted = pressure by lever. Take lever in inches. The answer is in inch-tons.

This power to be resisted is the strength of the rudder, and the strength of the rudder is its moment of inertia. The M.I., assuming rudder stock to be circular, is $\frac{\pi d^3}{16}$ or $\frac{3{\cdot}1416 d^3}{16}$ multiplied by the tensile strength of the material, allowing an ample factor of safety.

$$\text{Moment to be resisted} = \frac{3{\cdot}1416d^3}{16} \times \frac{\text{tensile strength}}{\text{factor of safety}}$$

The only unknown factor here now is d^3 (the diameter). By altering the equation somewhat it becomes—

$$D^3 = \frac{\text{moment to be resisted} \times 16}{3{\cdot}1416 \times \dfrac{\text{tensile strength}}{\text{factor of safety}}}$$

The answer is in inches. The moment to be resisted also determines the nett horse-power of the steering engine.

A unit of work = 1 foot-lb.
a horse-power = 550 units per second
= 33000 foot-lb. per minute

Assume that the rudder is to be put hard over in ten seconds. The nett horse-power required by the steering engine will be—

$$\frac{\text{moment to be resisted}}{550 \text{ units} \times 10 \text{ seconds}}$$

If this equation is followed out, we find that the slower the rudder has to be turned the less is the power required, and *vice versâ*. To the nett horse-power has to be added power to overcome friction of the engine, of the tackle, of the quadrant, etc.

Horse-power.—The form of the ship and the design and horse-power of the machinery are so interdependent that there must be a joint interest between shipbuilders and engineers if the vessel is to have the best results. It is in the province of the naval architect to determine from calculations and experience of former vessels the amount of horse-power necessary to obtain the required speed. It is in the province of the engineer to use this horse-power to its greatest advantage in the arrangement of boilers, engines, shafting, and screw or paddle. The horse-power in most common use is the indicated horse-power, or I.H.P. Besides this, there are the effective, or E.H.P., and the nominal, or N.H.P. The actual resistance of the ship to progress through the water is measured by the E.H.P.; that is, if a vessel was being towed, the measure of the strain on the tow rope is the actual resistance. The I.H.P. is the measure of the steam power as it enters the engine from the boilers. Of this power perhaps only 50 or 55 per cent. is used in driving the vessel forward; the rest is lost in friction, energy required for actual working parts, and in the slip of the screw.

To understand "slip," a simple illustration may be helpful. Stand in a small rowing boat, and by pushing against a floating log of timber, endeavour to propel the row boat. It will be found that while we have pushed the boat forward we have also pushed the log backwards. The screw, revolving through the water, which is a yielding substance, pushes part of the water back while it pushes the boat forward. The percentage of power left to push the vessel forward is its propulsive coefficient. Thus where 45 per cent. is lost through various causes, the vessel has a propulsive coefficient of 55. Twenty per cent. may be lost in the cylinders, etc., and 25 per cent. in the propellers.

I.H.P. = steam pressure × area of pistons, length of stroke and number of revolutions divided by 33,000.

$2nl$ = speed of piston per minute;
n = number of revolutions;
l = equal length of stroke.

One knot per hour = 101 feet per minute. Thus $8\frac{1}{2}$-knot speed is, roughly, 850 feet per minute.

1 horse-power = 33,000 foot-lb. per minute.
The amount of work necessary depends on the resistance
∴ horse-power = resistance × speed in feet per minute divided by 33,000

The resistance is measured in pounds. Froude has found that for ordinary painted ships' bottoms the frictional resistance at 6-knot speed is about $\frac{1}{4}$ lb. per square foot of immersed or wetted surface. This frictional resistance forms by far the greatest resistance which the vessel has to overcome up to high speeds, say 15 to 20 knots, and even here it forms about 50 to 60 per cent. of the total resistance. At, say, 8-knot speed the frictional resistance is 80 per cent. The total resistance of a vessel is made up of—

1. Frictional resistance.
2. Eddy-making resistance.
3. Wave-forming resistance.

The eddy-making resistance is about one-tenth of the frictional resistance. For the resistance due to the formation of waves, it has been found impossible to formulate a law which will be practically useful.

Resistance varies as the square of the speed. Using Froude's value for frictional resistance as $\frac{1}{4}$ lb. per square foot at 6-knot speed, the frictional resistance for any vessel = square feet of wetted surface × $\frac{1}{4}$ lb. per square foot × $(\frac{1}{6}\text{ speed})^2$.

The amount of wetted surface is found from the formula—

$$\text{W.S.} = (L \times D \times 1{\cdot}7) + (L \times B \times C)$$

L = length between perpendiculars;
D = moulded draught;
B = moulded breadth;
C = block coefficient.

In the resistance equation one-sixth of the speed in knots per hour is taken, because $\frac{1}{4}$ lb. per square foot was at 6-knot speed.

Having found the frictional resistance, assume eddy-making resistance as an added tenth, and wave-making resistance a percentage varying according to the speed, proportions, and form of the vessel. In a slow ship it may be about 10 per cent. of the frictional. In very fast ships, where the proportions are not good, such as driving a short vessel at a high rate, the resistance caused by the waves may be as much as the frictional resistance. There are in screw steamers other resistances, which we will not enter upon here. Having determined the total resistance, the E.H.P. may now be found, as it is directly dependent on the resistance. This E.H.P. is a certain proportion of the I.H.P., perhaps one-half. This determines the I.H.P. The N.H.P. is a figure solely employed for official returns, and is no measure of the vessel's power.

$$\text{N.H.P} = \frac{7 \times \text{area of pistons} \times \text{speed of pistons}}{33000}$$

The 7 is the steam pressure which is assumed for every vessel, although in some it may be 100–200 lbs. per square inch.

The speed of piston is in feet per minute.

Comparative Results.—To determine a vessel's I.H.P., the universal method is by comparison from other similar vessels, first from the midship-section area, and secondly from the displacement. The mean of the two results will give the probable I.H.P. required.

$$1.\quad \text{I.H.P.} = \frac{\text{speed}^3 \times \text{area of immersed mid-section}}{\text{mid-section performance coefficient}}$$

$$2.\quad \text{I.H.P.} = \frac{\text{Speed}^3 \times \sqrt[3]{\text{displacement}^2}}{\text{displacement performance coefficient}}$$

These coefficients are obtained from actual results of previous vessels.

$$\text{Midship performance coefficient} = \frac{\text{speed}^3 \times \text{area mid-section}}{\text{I.H.P.}}$$

$$\left.\begin{matrix}\text{displacement performance}\\ \text{coefficients}\end{matrix}\right\} = \frac{\text{speed}^3 \times \sqrt[3]{\text{displacement}^2}}{\text{I.H.P.}}$$

From 1 and 2 may be deduced, if the I.H.P. is known, the probable speed; thus—

$$1.\quad \text{Speed} = \sqrt[3]{\frac{\text{I.H.P.} \times \text{mid-section performance coefficient}}{\text{area of immersed mid-section}}}$$

$$2.\quad \text{Speed} = \sqrt[3]{\frac{\text{I.H.P.} \times \text{displacement performance coefficient}}{\sqrt[3]{D^2}}}$$

For an ordinary merchant vessel of, say, 400 feet long, the mid-section performance coefficient will vary from about 600 at 11 or 12 knots to about 500 at 15 knots.

The displacement performance coefficient will vary from about 270 for 11 or 12 knots to about 250 for 15 knots. At 15 knots for a vessel of 600 feet long, the coefficient would be about 300. For a small steamer of 170 feet long at 13 knots, the coefficient would be about 210. The knots by the screw is always more than the speed of the ship by the amount of the slip.

$$\text{Knots by screw} = \frac{\text{total revolutions by counter} \times \text{pitch}}{6080}$$

Deduct from this the knots actually steamed, and the difference will give the slip of the screw.

Assume that the I.H.P. of a steamer is known for a certain speed at a certain displacement, and it is required to find what speed the same I.H.P. will drive another similar steamer of different displacement.

$$\text{New speed} = \text{old speed} \times \left(\frac{\text{old displacement}}{\text{new displacement}}\right)^{\frac{1}{6}}$$

Assuming that the new vessel is to be driven at the same speed, and it is required to find the I.H.P. necessary.

$$\text{Then new I.H.P.} = \text{old I.H.P.} \times \left(\frac{\text{new displacement}}{\text{old displacement}}\right)^{\frac{7}{6}}$$

PROPELLERS.

The three propellers in use now are—

1. The jet propeller;
2. The paddle-wheel propeller;
3. The screw propeller.

The first may be treated briefly, as it is not of much importance. In the jet propeller water generally enters under the ship's bottom. It is churned to a high velocity, and forced out through small nozzles at after end. Nozzles may be turned either way, driving ahead and astern. There is great difficulty to get a continuous stream, and turbines are used to give the required velocity to streams. The nozzles are kept a little above the water, perhaps a few inches. With one jet ahead and the other astern, the boat can turn.

NOTE.—(1) Inlets must be arranged so that water enters easily. (2) Easy flow from inlet to turbines and outlet.

If engine is to drive from rest ahead or astern, the flow of water is practically dead, instead of coming to engine at speed of ship.

The jet propulsive coefficient is about 30.

The screw propulsive coefficient is about 55.

Tried against a similar ship with same boilers and twin screws, speed coefficient 60 per cent. better. Another gave 50 per cent. better for expenditure of power. This may not necessarily give twice the speed, but it might be 1 knot or 1½ knot, according to speed and I.H.P.

Advantages claimed are—

1. Freedom from damage by wreckage or fouling or grounding.
2. Greater control by commanding officer.

Paddles.—The chief divisions of the paddles are side and stern.

They cannot be applied so readily to cargo boats or ocean liners, because *where draughts vary* the floats might be deep in water or hardly touching. Efficiency of paddle is greatest at a certain constant immersion. Also, again, rolling affects them, as one paddle may be out of water and another deep in. Coal burning or going-out light alters draught. Rolling strains engines, as one paddle offers great resistance while other is racing. They require also great breadth, but they are found very useful in excursion steamers, as they are very fast, easily started, and manœuvred.

Paddles and jets give direct sternward momentum. Speed of floats depends on diameter of wheel. If slip is known to be, say, 25 per cent., and speed required, say, 20 knots, then diameter of wheel would be arranged with number of revolutions to give that speed in feet per second of a blade going through the water, allowing for the 25 per cent. slip. The position of the paddles is most important. They ought to catch the top of a wave, as particles of wave then have most sternward motion, so they are put a little aft of midship, or lines are designed for wave line to suit paddle wheels. Paddles are put astern where there is very little water, in order to get the big wave at stern. Bottom of floats about one-third draught. As one paddle is entering the water another should be leaving, and middle should be vertical. The churning of water in old paddle wheels is greatly done away with by feathering the floats. Upper edge of float light should be 1 or 2 inches below water when vertical.

Number of floats = number of feet in diameter of wheel. Breadth of float about 1 inch per foot of diameter. In feathering floats only half the number are used, but they are twice as large. Breadth of paddles about half-breadth of boat.

Screws.—The mechanical power of a screw consists of a spiral thread revolving round a cylinder, and it combines the properties of the lever and the inclined plane. The screw blades as they sweep round drive a stream of water astern, and the reaction of that water produces a forward pressure which is transmitted to the ship through the shaft, and drives her ahead. A propeller may have two, three, or four blades; but every time a blade passes the stern it causes severe vibration. If there are an even number, one will be crossing the stern above and the other below, and by crossing in a different direction, counterbalance each other and reduce the vibration.

The pitch is the length of a complete turn measured parallel to the axes. Speed of screw per second is the number of revolutions × pitch. Face of blade is the aft side (straight); back of blade is the fore side (rounded).

Propeller blades must not break water.

Blade area, pitch, and diameter are all essential. A vessel was fitted with a two-bladed propeller, 5½ feet diameter. This was taken off, and a two-bladed propeller, 4½ feet diameter, with 6 inches more pitch and 50 square feet more area, was substituted. The vessel with the same I.H.P. obtained 3 knots more speed. Another, which had two four-bladed propellers, got 14½-knot speed. Two of the blades were removed, and the same I.H.P. gave 15¾ knots.

Next, the diameter was reduced, the pitch increased, and blade area reduced. Four blades were again fitted. This gave 15¾ knots.

Next, two blades with nearly the same diameter as the first, but pitch greatly increased (3 feet) and blade area reduced, gave about 16 knots. This caused excessive vibration, and the four blades of small diameter and large pitch were finally adopted.

The most efficient pitch ratio—that is, the ratio of the pitch to the diameter—has been found for ordinary vessels to be about 1·4.

QUESTIONS ON CHAPTER IX.

Ques. A vessel on her steam trials is found to vibrate excessively. To what possible causes may this be attributed? What steps should be taken to discover the cause and to remedy the defects?

Ans. If the rates of revolutions of the engines approximate to multiples of the period of vibration of structural parts of the vessel, excessive vibration will result. High-speed vibrations are most marked.

The chief cause is to be found in the unbalanced moving parts of the propelling machinery.

So far as vibration is concerned, a ship may be compared to a bar of varying cross-section, and its natural period of vibration depends upon the structural arrangement and distribution of material. If the rates of revolutions of the engines approximate to multiples of the period of vibration, then the successive impulses due to the unbalanced moving parts gradually increase the extent of vibration. If the engines are not running at the rate approximating to the natural period of vibration, the vibrations will be much reduced.

Causes of Excessive Vibration.—(1) Moving parts of machinery not properly balanced.

(2) Badly designed propellers.
(3) " " engine seating.
(4) " " thrust "
(5) " " tunnel stools.
(6) Weakness or scarcity of aftermost stools.
(7) Any sudden break in the longitudinal or structural strength.
(8) The line of shafting being out of line.

To remedy Vibration. Endeavour to find whether it is caused by propellers, structural weakness, or machinery.

(1) If it is on account of propeller, it may be remedied by changing propeller.

(2) If engine seating is loose, make it perfectly tight.

(3) If unbalanced parts of moving machinery, make these to balance perfectly.

(4) If any sudden break, say, in a stringer, it must be gradually tapered or reduced, to remedy the abruptness.

(5) If aftermost floors, they must be made perfectly rigid to withstand the strain.

(6) It is advisable to have the engines which will give the speed most frequently required at rates of revolutions not approximating to multiples of the period of vibration.

CHAPTER X.

CURVES—COEFFICIENTS—DEFINITIONS—APPROXIMATIONS.

Curves.—On the displacement sheet are drawn the displacement curve; the vertical C.B. curve; the longitudinal C.B. curve; the transverse metacentre; the longitudinal metacentre; area of midship section; C.G. of water-planes; and tons per inch.

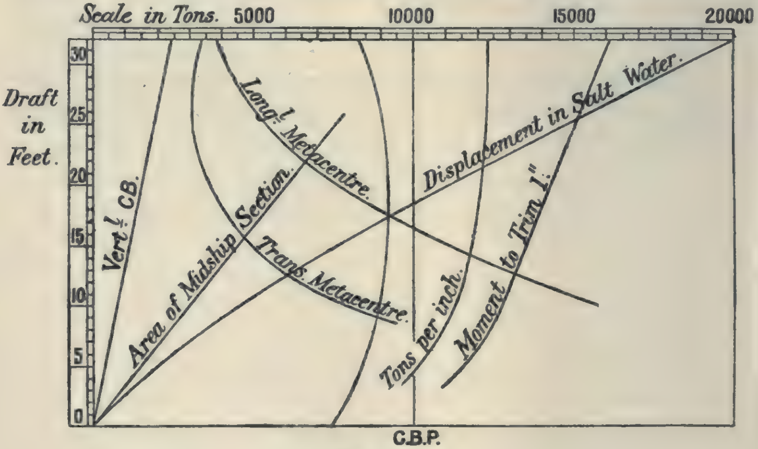


Fig. 106.

In each case a calculation is made either up to or for certain water-lines, and the results set out at these water-lines on a convenient scale. A line passed through these spots gives a curve of that calculation. The only one requiring special notice is the transverse metacentre. This curve is set up from the curve of vertical C.B., as the calculation of the metacentre is found at a certain distance from the C.B. In the diagram it is shown as an ordinary curve with the rest, but it is sometimes shown as a separate diagram and called the metacentre diagram. In this diagram a line is drawn at 45°, and where it cuts the various water-lines perpendiculars are drawn. From these points of intersection, the vertical C.B.'s below each water-line are set down, and then the distance of M above the C.B. is set up from the curve of C.B. At any intermediate water-line the value of the metacentre can be at once determined.

Note that the displacement curve is very straight, except at the beginning, where there is a slight hollow.

The vertical C.B. curve is also almost a straight line.

The longitudinal C.B. curve at the deeper draughts had a tendency to go aft. The transverse metacentre is generally a very hollow curve, its value increasing rapidly at the lighter draughts. The longitudinal metacentre curve has similar characteristics.

The areas of midship section curve is very like the displacement curve. The curve of tons per inch is very like the actual midship section of the vessel.

COEFFICIENTS.

The block coefficient is the relation which the actual volume of displacement bears to the volume which would be displaced by a rectoid of the same length, breadth, and draught. Thus, if a vessel is 0·75 coefficient, it means that it would only displace three quarters of the amount of water which a log or rectoid of the same dimensions would displace. The other quarter has been lost by cutting away the ends and bilge to give it the form of a ship.

The midship coefficient is the relation which the actual immersed midship section bears to the rectangle which has breadth and depth of ship for its sides before the bilge was cut away to ease the ship's rolling, etc.

The prismatic coefficient is the block coefficient divided by the midship coefficient.

The water-plane coefficient is the relation which the actual area of the water-plane bears to the area of a rectangle which has length and breadth of ship for its sides.

The block coefficient is sometimes called the displacement coefficient or the coefficient of fineness.

The tonnage coefficient is approximately the block coefficient plus 0·03.

These are the principal coefficients in ordinary use.

To find the displacement of a vessel if the block coefficients and dimensions and draughts are known, multiply length by breadth by draught by block coefficient, and divide by 35 or 36, according to the water the vessel is floating in.

DEFINITIONS.

Moment to alter trim one inch is the number of foot-tons required to alter the difference between the forward and after draughts by one inch; *e.g.* half-inch less forward and half-inch more aft give a difference of 1 inch in the trim.

Tons per inch is the number of tons required to increase or decrease the draught by one inch.

Atwood's formula is: Moment of statical stability = volume of wedge by perpendicular distance between C.G. and wedges, − total volume of displacements × BG sine of angle of heel; or shortly $= v \times hh - V \times BG \sin \theta$.

Freeboard is the amount of ship's side above the water amidships, measured from the top of the upper deck in ordinary vessels.

Centre of lateral resistance is the centre of resistance of a vessel to be dragged broadside through the water.

Centre of effort is the centre of gravity of the areas of all the sails of a vessel.

Ardency is the tendency of a sailing vessel to fly up into the wind. This happens when the centre of effort is aft of the centre of lateral resistance.

Slackness is the converse of the above.

Transverse metacentre is the intersection of the vertical through the C.B. of an inclined ship with the vertical through the C.B. in the upright condition.

Metacentric height is the distance between centre of gravity and the metacentre or G.M.

Stiffness is caused by having a large G.M. The vessel is very hard to incline, but when she is put over as soon as the pressure is removed she comes back very suddenly. This shock has been known in some vessels to break the masts.

Tenderness or crankness is caused by having a small G.M. In this case any little external force is enough to make the vessel heel so that she is either inclined with a constant list or she is rolling from side to side continuously.

Steadiness is gained by having a moderate G.M. The vessel in this case requires some considerable external force to cause her to heel, and she goes over slowly and comes back at the same rate.

Dynamical stability implies, because of the word dynamical, *work done* against gravity. When the vessel is inclined, the C.G. of the vessel, although in the same place in relation to the boat, has been raised to a higher plane and the C.B. at the same time been lowered. The amount of work necessary to raise the C.G. and to lower the C.G. is the measure of the dynamical stability.

$$\text{Work done} = \text{weight of ship} \times \text{rise of C.G.} + \text{lowering of C.B.}$$

In a curve of stability the area of the curve up to any angle represents the vessel's dynamical stability at that angle.

Moseley's formula uses the wedges, as did Atwood's, for the statical stability. The emerged wedge has had its C.G. raised during inclination, and the immersed wedge has had its C.G. lowered. The vertical distance between these C.G.'s is represented by $(gh + g_1h_1)$; v is the volume of the wedge, V = volume of displacement. Then—

$$\text{dynamical stability} = \frac{v(gh + g_1h_1) - \text{V.BG vers } \theta}{35}$$

Residuary resistance is the resistance other than frictional which a vessel offers to progress through the water.

Deadweight is the difference between the light weight of a ship and the total displacement of a loaded ship. In other words, it is the weight of the cargo carried.

Equilibrium.—When the metacentre is above the C.B. the vessel is in stable equilibrium.

When the metacentre and the C.G. coincide, the vessel is in neutral equilibrium. When the metacentre is below the C.G. the vessel is in unstable equilibrium.

Oscillation is the term used to express the rolling motion of a ship from port to starboard, and *vice versâ*.

Hogging occurs when a vessel is on the crest of a wave, and there is a tendency for the ends to droop.

Sagging occurs when a vessel is in the hollow or trough of a wave, and there is a tendency for the midship portion to droop.

Working strength = utmost safe bearable stress for ordinary use
Proof strength = utmost bearable stress without loss of strength
Elastic strength = utmost bearable stress without set
Ultimate strength = utmost bearable stress without breaking
Stress = intensity of load
Strain = measure of alteration caused by stress

APPROXIMATIONS.

Stability of a ship varies as the square of its breadth.

I.H.P., and therefore weight of machinery at low speeds (up to 14 or 15 knots), varies as the cube of the speed.

Weight of coal varies as the square of the speed or directly as the I.H.P.

Bending moment if dimensions remain constant increases as the square of the length.

Waves may be taken as the height = one-twentieth of the length up to, say, 600 feet long. Over 600 feet height is not so great a proportion, and therefore vessels of and over this length are not subject to such severe stresses as the smaller vessels.

Wetted surface in square feet = $1{\cdot}7\,\mathrm{LD} + \frac{\mathrm{V}}{\mathrm{D}}$ or $15{\cdot}6\sqrt{\mathrm{W.L.}}$

L = length of ship
D = mean draft
V = volume of displacement
W = displacement in tons

Block Coefficients—

Battleships = 0·6 to 0·65
fast cruisers = 0·5 „ 0·55
fast mail steamers = 0·5 „ 0·55
ordinary steamships = 0·55 „ 0·65
cargo vessels = 0·65 „ 0·82
sailing vessels = 0·65 „ 0·75
yachts = 0·35 „ 0·45

Vertical centre of buoyancy varies from eight-twentieths to nine-twentieths of moulded draught below the load-line, therefore from eleven-twentieths to twelve-twentieths of moulded depth above the base, or—

$$\text{C.B. below L.W.L.} = \tfrac{1}{3}\left(\frac{D}{2} + \frac{V}{A}\right)$$

when V = volume of displacement
A = area of load water-plane in square feet
D = mean moulded draught

Water-plane coefficient at load draught—

vessels with fine ends = 0·7
vessels of ordinary form = 0·75
vessels with bluff ends = 0·85

Moment of inertia of a ship's water-plane about the centre line = nLB^3

L = length
B = breadth
n = 0·04 in extremely fine ships
n = 0·05 in ordinary ships
n = 0·06 in very full ships

Transverse metacentre above C.B.

$$= A \times \frac{B^2}{D}$$

B = breadth
D = mean draught
A = 0·08 to 0·1 (say 0·09 @ 0·75 coefficient)

For a 540-feet vessel at 0·65 coefficient, and at load draught 0·08, gave the correct B.M.

G.M., or metacentric height—

	ft.	in.		ft.	in.
harbour vessels, tugs, etc. =	1	3	to	1	6
protected cruisers =	2	0	,,	2	6
battleships =	3	6			
shallow-draught steamers =	12	0			
merchant steamers =	1	0	to	3	0
sailing vessels =	3	0	,,	3	6
minimum at launching =	1	0			

Vertical C.G. of ship's structure

= 0·65 to 0·8 moulded depth

Longitudinal metacentre above C.B.

$$= 0{\cdot}0735 \times \frac{A^2 \times L}{B \times V}$$

L = length in feet
B = breadth moulded
V = volume of displacement
A = area of load water-plane

Moment to trim 1 inch—

$$\frac{\text{length} \times \text{displacement}}{n \times \text{draft}}$$

for fine vessel, $n = 190$
for ordinary vessels, $n = 180$
for cargo vessels, $n = 172$

This is a most useful and important approximation.

For a rough approximation, take moment to trim 1 inch as $= \frac{1}{11}$ displacement.

Tons per inch at load—

$$\text{fine vessels} = \frac{L \times B}{600}$$

$$\text{medium vessels} = \frac{L \times B}{550}$$

$$\text{cargo vessels} = \frac{L \times B}{500}$$

very roughly $= \frac{1}{10}$ of length

Total resistance of a steamer varies—

up to 11 knots, as the square of the speed
at 16 ,, ,, cube ,, ,, ,,
18–20 ,, ,, 3·3 power ,, ,,
22 ,, ,, 2·7 ,, ,, ,,
25 ,, ,, square of the speed
30 ,, ,, 1·83 power ,,

Wave-making resistance varies—

up to 11 knots, as the square of the speed
12–13 knots, as the cube of the speed
14–15 ,, ,, 4th power of the speed
18 ,, over the 5th power of the speed

Frictional resistance at

12 knots = 80 per cent. total resistance
16 ,, = 70 ,, ,, ,,
20 ,, = 50 ,, ,, ,,
30 ,, = 45 ,, ,, ,,

Coal per I.H.P. per hour = 1·5 lbs. to 1·25 lbs.

NOTE.—A vessel 460 feet long at 25 feet draught and steaming 12 knots has made a voyage to Australia on a mean consumption of 1·17 lbs. per I.H.P. per hour.

Total Weight of machinery is about $\frac{1}{5}$ ton per I.H.P. for forced draught boilers to $\frac{1}{4}$ ton per I.H.P. for natural draught boilers (screw steamers).

Weight of hemp hawser in cwts.

$$= \frac{\text{diameter}^2 \times \text{length in fathoms}}{450}$$

Strength of hemp hawser in tons

$$= \tfrac{1}{5}\ \text{diameter}^2$$

Passenger capacity of a lifeboat

$$= \tfrac{1}{14}\ L \times B \times D$$

Load water-plane coefficient—

Add to block coefficient, 0·09 to 0·10

NOTE.—Approximations can only be applied to ordinary shaped and proportioned vessels, *and at load draughts.*

QUESTIONS ON CHAPTER X

Ques. What is a metacentric diagram? Sketch and describe same.

Ans. A metacentric diagram deals only with the position of the transverse metacentre for all possible draughts in the upright position. Construct scale AB, and run water-lines at, say, 4 feet, 8 feet, 12 feet, and 16 feet. It is necessary to construct the curve of the C.B. first, to aid us in ascertaining the metacentric curve.

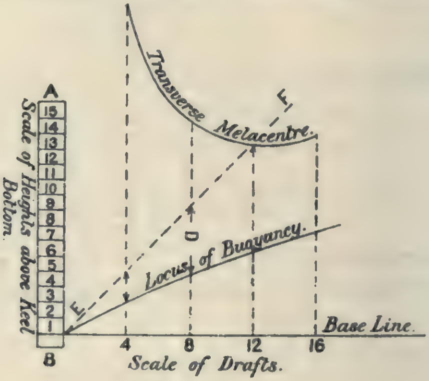


FIG. 107.

Run line EF at an angle of 45°. Calculate the position of the C.B. at each respective draught above keel or below L.W.L., if vessel is on an uneven keel. Set off these distances below line EF at successive draughts, and draw curve, which is termed the locus of C.B. Having obtained positions of C.B., the metacentric heights can now be ascertained by finding the moment of inertia of the water-lines about the centre line, which, when divided by volume of displacement at the particular draught, gives the height of M.B. Supposing the results of calculations for M.B. are at 4-feet draught, 19 feet above C.B.; at 8-feet draught, 9·2 feet above C.B.; at 12-feet draught, 5·75 feet above C.B.; at 16-feet draught, 4 feet above C.B.

At the 4-feet draught, draw vertical line intersecting the curve of buoyancy, and extending above it; set up the height of M.B., say, 19 feet, which then shows position of metacentre to be 22 feet above bottom of keel, repeating same process at each water-line. Now run curve as required, which enables us to read off heights of metacentre at any draught.

CHAPTER XI.

LAYING OFF.

Preliminary.—When the draughtsman begins to design his ship, he is supplied with the following information:—

1. Length between perpendiculars.
2. Breadth moulded.
3. Depth moulded.
4. Draught moulded.
5. Displacement required.

The midship section is first determined. The coefficient obtained divided by the block coefficient, which can be got from the given displacement, will give the prismatic coefficient. In the drawing office are kept a number of curves of immersed areas for previous vessels. These curves are all drawn to one length of, say, 20 inches, and one breadth of, say, 5 inches. The ratio of the curve of immersed areas to the circumscribing rectangle gives the prismatic coefficient. The length being 20 and the breadth 5 make the block = 100. If the area of a curve under notice is 75 square inches, the prismatic coefficient of that vessel is 0·75. Assuming the desired prismatic coefficient is 0·76, a curve is drawn similar to whatever ship is determined upon. This curve has ordinates to suit the displacement sections. The readings of these ordinates give the immersed area of the sections. The load water-line is next determined, and is set off on the body plan. By dividing the draught into the immersed area of each section, the mean breadth of the section is found. These mean breadths are also set off on the body plan. Having a spot for the load line, and a rectangle giving the area of the section, it is now easy to draw in the complete body plan. Having drawn this, the rest of the lines can be obtained and the plan completed.

EXPLANATION OF TERMS.

Length between perpendiculars is the length of the ship measured from the fore-side of the stem to the after-side of the stern-post at the line of the upper deck.

Breadth moulded is the greatest breadth of the ship over the frames, that is before the plating is put on.

Depth moulded is the depth amidships from the top of the freeboard (usually the upper) deck beam at side to the top of the keel.

Amidships is at the point of greatest breadth.

Lines are drawn on three planes. The vertical longitudinal plane is called the sheer plan.

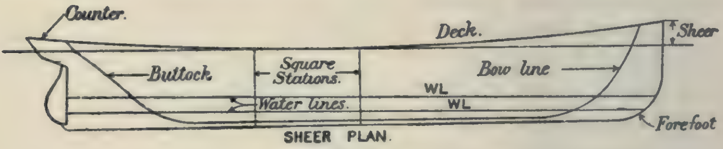


FIG. 108.

The horizontal longitudinal plane is called the half-breadth plan.

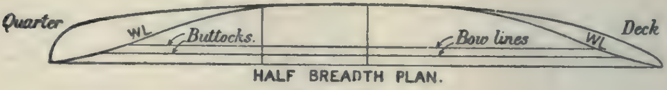


FIG. 109.

The transverse sections are drawn on the body plan.

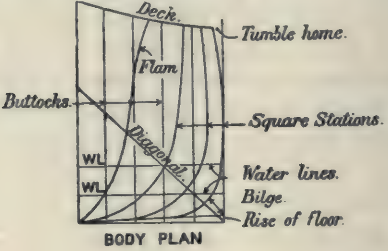


FIG. 110.

On the sheer plan, lines representing the vessel sliced right fore and aft, say, 4 feet, 8 feet, 12 feet, out from the centre line are drawn. The traces of these forward are called the bowlines; aft are called the buttocks.

Sheer.—Almost all vessels have their deck lines continually rising from midships forward and aft. The gradual rise is termed the sheer.

Rise of Floor.—The bottom of ships is generally a straight line for some distance from the centre of the body plan. If the boat has, say, 12-inch rise of floor, a spot 12 inches above the base is measured at the side of ship. A line from this spot to the centre gives the rise of floor. All the sections run into this line.

Bilge is the round of the section between the rise of floor line and the side.

Tumble home is the fall in of the section amidship at the upper deck.

Flam is the throw out of the forward sections at the upper or forecastle decks.

The A.P. and F.P., or after perpendicular and forward perpendicular, are respectively vertical lines at the aft side of sternpost and the fore side of stem on the line of the upper deck.

Fairing.—A vessel is faired by means of water lines, sections, buttocks, and sometimes diagonals. Note on the diagrams the forms of each of these lines. When the under-water sections are drawn on the body plan the deck line is set off on the half-breadth plan, and the sheer of the deck is drawn on the sheer plan. The sheer heights are now transferred to the body plan, and the half-breadths of the deck are measured and set off at the respective stations on it. The under-water sections are next drawn up to meet the deck spots. The body plan is now finished roughly, but it requires to be faired. Water-lines, say 2 feet apart, are drawn across it. The half-breadths of each section are measured and set out at their respective stations on the half-breadth plan. If the body plan is fair, a line drawn through these spots will give a fair curve. If it is not a fair curve, the sections on the body plan are corrected. The buttocks and the bowlines are now drawn on the half-breadth plan and body plan. Where these cut the sections their heights are lifted and set up on the sheer plan at their stations. The water-lines having been drawn on the sheer plan, the intersection of the buttocks and bowlines with the water-lines on the half-breadth plan are projected to the sheer plan and spotted on the corresponding water-lines. Lines drawn through these spots on the sheer plan should, if the sections and water-lines are correct, give fair curves. If they are not fair, the sections and water-lines are corrected. To insure further accuracy diagonals are sometimes employed.

Method of determining the Sheer.—The forward sheer is the height the freeboard deck is at the F.P. above the moulded depth; after sheer height at A.P. above moulded depth. Sheer forward is generally about twice the sheer aft.

Thus forward sheer = 6 feet
aft sheer = 3 ,,
mean sheer in above case is $\frac{6+3}{2} = 4\frac{1}{2}$,,

Mean sheer in inches is obtained by adding 10 to one-tenth of the length of the vessel.

Thus, if vessel is 360 feet long, mean sheer = $\frac{360}{10} + 10 =$ 46 inches; 200 feet vessel = 30 inches; 250 feet = 35 inches; 255 feet = $35\frac{1}{2}$ inches; 500 feet = 60 inches; and so on.

Note the similarity between the sheer in inches and the length of the vessel in feet. To this mean sheer Lloyd's allow an addition of half the sheer. Thus, if mean sheer = 48 inches there may be added to it 24 inches, making the mean sheer 72 inches. This mean sheer is half the sum of the forward and after sheers, therefore by doubling it we get the sum of the two sheers.

Sum of sheers = 72 × 2 = 144 inches
$\frac{1}{3}$ of total = 48 inches = after sheer
$\frac{2}{3}$ of total = 96 inches = forward sheer

To draw in the Sheer.—The sheer should be part of the circumference of some huge circle or parabola. Some builders for economy keep the sheer amidships as flat as possible and spring it up at the ends to the required height, the height being as large as permissible, more draught and consequently carrying power being obtained by having greatest possible sheer. To insure a proper sheer the freeboard tables specify that at one-eight the length of the vessel from either end the sheer must be at least 55 per cent. the end sheers. The following diagram is simple and gives an approximately true form of sheer:—

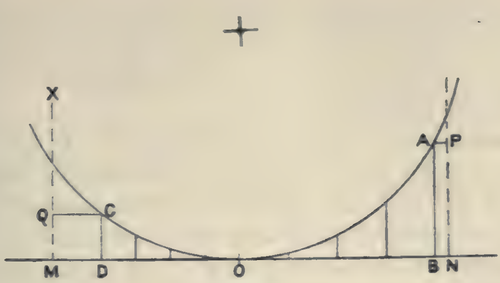


FIG. 111.

With centre Q and a large radius describe an arc of a circle. Draw MN tangent to the circle. At any points M and N erect perpendiculars, say, MX, NY. On NY measure NP = forward sheer. On MX measure MQ = after sheer. Project PA and QC parallel to MN, cutting the arc in A and C. AB and CD are perpendicular to MN. O is the point of lowest sheer (generally amidships). Divide OB and OD into four equal parts and erect perpendiculars. These heights are set off at equivalent sections on the sheer plan, and the line is faired to please the eye.

Particulars to Loft.—The lines are now completely finished in the drawing office. These must now be laid down full size on the loft floor for fairing and transference to the boards. The loftsman is supplied with the tracing of the stem, stern-post, stern and rudder frame, with figured dimensions on each. In twin screw steamers and others with any exceptional form additional information may be required. A table giving length, breadth, depth (all moulded), and frame spacing is also given. A certain number of water-lines—perhaps every 2 feet—are taken, and the breadths of each at, say, every fifth or tenth frame are set down on the table. The heights of decks, buttocks, bowlines, etc., are also given. The loftsman proceeds at once to draw in the stem, stern-post, and all forgings or castings full size, and to prepare batten moulds of these to send to the makers. The body plan having been faired in the loft, the sight edges of plating are now drawn on it. At midships they are taken from the midship section, and the stringers and deck lines on the body plan form a guide for getting in the plate lines. They should be kept as near as possible square to each section, as this gives the plating the minimum of curvature, and makes the plates easier to order, to make, and to fit, besides having least waste. By lifting the heights above the base where each sight edge crosses each section, and projecting these on the sheer plan, the landings are faired.

The model is generally a half-block on ¼-inch scale. It shows the frames, plate edges, butts, stringers, decks, and all openings in the shell, and also the thickness and taper of plates, according to classification society rules.

The floors in a double-bottom ship are easily obtained and set off. Where the vessel is single bottomed the procedure is similar, but more difficult. The line of the midship floor is obtained from the midship section. The spread of the floors at the extremities of the ship is next fixed upon. Where the line joining the extremities with midships cuts the sections will be the floor endings for each section. This line generally runs level for some distance amidships, and then runs up to the extremities. This line can be faired on the sheer plan. The curve up of the inside of floors can be faired by running buttocks on the sheer plan.

The lines of all deck beams at side are shown on body plan. For this purpose a beam mould requires to be made. From the sheer plan the deck at side of the freeboard deck can be at once transferred to the body plan. Decks are parallel at centre and not at side. By setting the beam mould to the deck at side at each section the deck at centre can be obtained.

From these centre spots measure down the next deck. Set the mould to these centre spots, and where it crosses each section will give the line at side for that deck. Beam moulds are now made for each deck, and the lengths of beams at each frame are marked on them.

Scrieve Board.—The body plan on the loft being now finished, it must be transferred to some handy place for the plater to refer to. The scrieve board is an exact copy of the loft body plan, with all the lines scrieved or cut into the wood instead of merely chalked. The scrieve board itself is composed of a number of boards securely fastened together. It is kept alongside the bending slabs.

Beam camber allowed by classification societies is ¼ inch for every foot of breadth. If a vessel is 40 feet breadth, the beam at centre would therefore be 10 inches above beam at side. The beam camber is, like the sheer, a part of the circumference of a circle. It may be obtained in a number of ways. Perhaps the simplest method is as follows:—

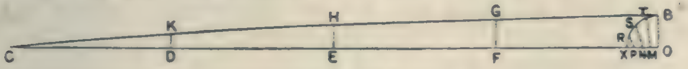


FIG. 112.

Let OC = half-breadth of vessel;
OB = camber.

With centre O and radius OB describe quadrant BX. Divide the arc BX into four equal parts at RS and T. Divide the radius OX into four equal parts at MN and P. Join PR, NS, MT. Divide OC (the half-breadth) into four equal parts, D, E, and F. At these points erect perpendiculars.

Make DK = PR
EH = NS
FG = MT

A line drawn through these spots will give a fair camber curve. By repeating for the other side the whole camber mould is obtained.

Expansion of the Stern. — Produce BC, and through the points which C_1, C_2, C_3 (cants) cut the upper and lower knuckle, erect perpendiculars on BC on sheer. On plan through the points where cants cut upper and lower knuckle erect perpendiculars on upper and lower rail perpendiculars. Measure off the lengths

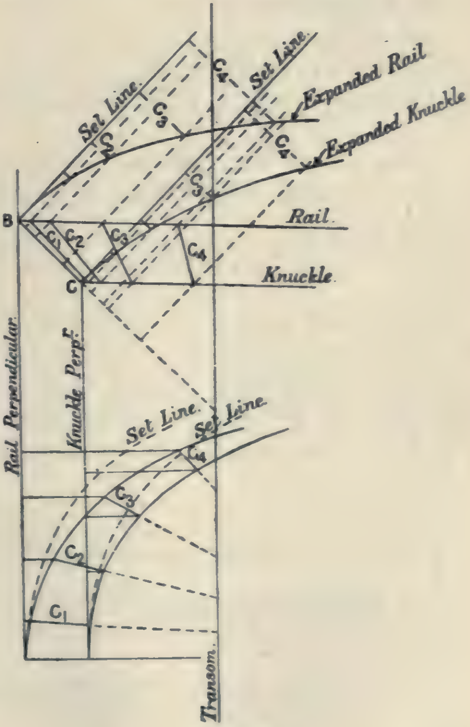


FIG. 113.

of the perpendiculars on the sheer DH, EK, FL, MN, O P,RS, and set them off on plan from these perpendiculars, viz. D, H, E, K, M, N, etc., giving the set-lines on plans. Girth round the set-lines on plan, and set off these points on the sheer set-lines. Each of these points is for a cant on the plan. From these points on the sheer drop perpendiculars to meet the set-line of that particular cant. The spots now obtained should give a fair curve, which will be the true form of the plate required for bending round the stern.

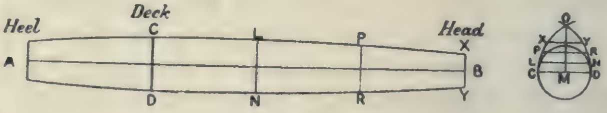


FIG 114.

Mast Expansion.—

AB = length of mast.

Diameter at deck is given.

Diameter at head is $\frac{5}{8}$ diameter at deck.

,, ,, heel ,, $\frac{3}{4}$,, ,,

Draw a circle with diameter = diameter at deck CD.

With C and D as centres and radius CD describe arcs cutting in O.

Draw a line, XY, parallel to CD and equal to diameter at head.

Divide OM from XY to CD into, say, three equal parts on the sheer plan; divide from the deck to the head into the same number of equal parts; set off O, P, M, N, etc., equal to OP, MN, etc. A line drawn through these points will give the true form of the mast. This operation repeated for heel work.

QUESTIONS ON CHAPTER XI.

Ques. Explain how the midship body is faired by contraction. Show that the method is correct, and state for which parts of the ship you would use this method.

Ans. On the base line of the sheer plan set off the spacing of the frames about one-eighth full size, *i.e.* the midship body of the ship for about two-thirds length.

No contraction is made vertically with the sheer heights, depth moulded, and water-lines.

Draw in the body plan full size, lifting the sheer heights for same from the sheer draught. This line should already have been drawn on contracted sheet.

Take the midship frames of the body plan, and set off diagonals square to the surface of the frames.

Measure, say 3 inches square off the surface of the midship frame, from the deck down to the keel.

From the point 3 inches out from frame, lift the frames on the diagonal line.

Set these spots off on the contracted half-breadth plan, working from the edge of the boards.

Do the same for the other diagonals, and get a series of curved lines, which draw fair.

If necessary, the body plan may be faired to agree with faired curved lines.

The one-sixth length forward, and one-sixth aft, would be fared full size and overlapped considerably on contracted parts.

It is easier to fair a short curve than it is to fair a long one. The body plan and the sheer plan (vertically) being full-sized, it is only in the spacing of the frames that the contraction occurs.

The curve of the frame remains the same, whatever spacing is adopted.

The parts of ship for which to use this method are—

In the flat of the ship, say for about half-length, when there is not much round in the water-lines.

Ques. Having given the deck at side line, in the sheer plan and in the half-breadth plan, show how you would obtain the line of deck at centre, and how you would proceed to lift from the body plan the lengths of the beams and the bevels of the beam knees on that deck.

Ans. (1) Run in the sheer plan the sheer at side.

(2) Run in the outline of the deck in the half-breadth plan.

(3) Lay off the camber of the ship's deck, full size, on the loft floor. Lloyd's require the camber to be $\frac{1}{4}$ inch per foot of length of beam.

(A) Lift from the half-breadth plan the half-ordinates of the deck at, say, every 10th frame.

(B) Set these points out square on each side of the centre in the camber curve.

(C) Stretch a line across from point to point, and measure the amount of camber due to the width for each section; and place these distances above the deck at side on their respective sections in sheer plan, which are points for the curve of the sheer at centre.

(D) Forward, the line will terminate at the inside of the stem, where we have the maximum sheer, and where the sheer at side and sheer at centre coincide.

(E) Amidships, the height of the sheer deck at centre, above the sheer at side, will be the full crop of the beam.

(1) Draw in the body plan the various square stations, the depth moulded, and the deck at side line.

(2) Make a half-beam mould to the crop of the deck; width of mould, about 11 inches.

(3) From the sheer plan, lift the heights of the deck at centre for each section above the depth moulded.

(4) Mark these heights on the centre line of the body plan above the depth moulded.

(5) Take the beam mould to the scrieve board, and lay it on the required beam, keeping the centre of the mould exactly in the centre line of the ship, and working from the upper edge of mould.

(6) Then mark off the length of the beam.

(7) Keeping the mould in the same position, and by marking on it the run of the frame, you get the bevel of the beam knee.

(8) The same thing is done for the other frames and beams in the fore body; and in the after body reverse the beam mould and work on the other side.

Ques. Describe the process of obtaining and fairing on the mould-loft floor the edges of the strakes of bottom plating. Explain how the plate edges should be arranged so that the plates shall have as little curvature as possible, and why such minimum curvature is desirable.

Ans. The edges are first arranged on the half-inch lines in the drawing office, the keel being settled, and also the garboard strake. These and the bilge strakes are decided upon first; the curvature at the bilge being as far as possible all on one strake. The space between the lower edge of bilge and upper edge of garboard strakes is then divided into a number of strakes.

The midship breadths of the strakes are maintained for about half length amidships, and the edges are run as square to the frames as possible, so as to reduce the sag to a minimum. (The edges are kept as clear as possible of stringers, keelsons, etc., and the boss plate is usually confined to one plate if possible.)

If the model is ready, the lines are often transferred to get a better idea of how they will appear on the ship, and any slight corrections needed may be made. The particulars of the edges are then supplied to the loftsman, either as offsets on buttocks or as girths on the frames. The loftsman runs them in on the body plan, and if they need fairing he does so by means of water-lines. The reason for reducing the sag or curvature of the edges as far as possible is to save cutting a lot of scrap off the plates.

Ques. When and for what purpose is a vessel laid off? From what plan is the information taken? and what information is usually given to the loftsman to enable him to proceed with the laying off?

Ans. The laying off of a vessel is proceeded with after the half-inch lines in the office have been designed to give the displacement which is required.

The purpose of laying off a vessel is: (1) To get it faired up, which is much more easily done on the boards to full size, than it can be done on paper, so that as soon as possible the loftsman should be supplied with a list of particulars, as given in the table below. (2) To get the correct shape of the frames for the frame turner, also correct positions and sheers, etc., of decks, stringers, plate edges, and tank tops.

List of Particulars given to Loftsman.—1. Length over all.

2. Length B.P.

3. Moulded beam.
4. Moulded depth.
5. Rise of bottom.
6. Fall in of bilge.
7. Tumble home of deck.
8. Size of forgings (stern-post, etc.).
9. Particulars of boss and shafting.
10. Form of extreme ends in profile.
11. Sheer heights and half-breadths of rail, knuckle, and deck.
12. Half-ordinates on water-lines and diagonals.
13. Buttock and bow-line heights on displacement sections.
14. Deck camber.
15. Positions of displacement sections and frame stations, parallel double body, rise of keel (if any), size of frames, and reverse frames.
16. Off-sets for plate edges, stringers, etc.
17. Half-breadth tank if double bottom, and height of midship tank knee.
18. Frame sheet and spacing.

Ques. What moulds would you have made for a large iron or steel ship? State the order in which you would have them sent out, with a view to best facilitating the work at the ship.

Ans. (1) **Keel Plate.**—A skeleton template is made for this class of plate, with the butts, the seams, the frames, and the holes to take the bars of centre girder, all marked on, the holes being drilled to enable plater to mark the holes easier on the plate.

(2) **Centre Girder.**—Same class of template as above.

(3) **Midship Floor Mould** is lifted from scrieve board, and is constructed very strong, made of 1-inch wood. Holes to take lugs for intercostals, frame bars, reverse bars, limber-holes, are spaced off and drilled; also position of man-holes, plate edges on tank top, etc., are marked on, ready for plater.

(4) **Beam Mould.**—This template is lifted from midship deck-line, and bevel of beams marked on, also plate edges of deck ready for beam setter.

(5) **Stem Mould.**—This template is made to the inside edge of the stem, which is laid down on mould-loft floor full size, to which mould is constructed; having decks, plate edges, frames, and holes drilled to take shell, marked on; also moulds for club foot are got out at each frame, etc.

(6) **Stringer Bar Moulds** are next got out, which are simply pieces of wood the length of the bar and the breadth of the flange, with holes spaced according to class.

(7) **Harpins and Sheer Ribbands**, etc., are lifted from scrieve board and laid down on mould-loft floor, and a batten is then bent round, and frames lifted ready for carpenters.

(8) **Stern Cants, Stern Plating.**—Stern laid down full size on mould-loft floor, and cants and stern-plate moulds are constructed. A wood structure of the stern is now built up to prove if the expansion of stern, etc., is correct.

Order of Moulds sent out.—Keel mould, centre girder, midship-floor mould, beam mould, stem mould, stringers, harpins, ribbands, etc., longitudinals, stern plating, cants, etc.

Ques. Distinguish between common and sheer harpins. How are each laid off and the bevels obtained?

Ans. **Sheer harpin** is an angle iron 3 inches × 3 inches, which runs along the sheer of the vessel 6 inches or 8 inches below the deck, generally fixed at the ends of the vessel, where the vessel has the greatest curvature.

Common harpins are the extremities of ribbands, and are made of wood (elm), but small in section.

To lay off a Sheer Harpin.—(1) Draw line AB on sheer and body plans, say 6 inches or 8 inches below the deck.

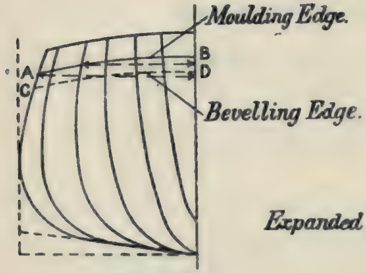


FIG. 115.

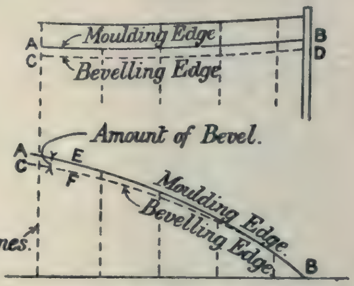


FIG. 116.

(2) Breadth of flange on body and sheer, obtaining bevelling edge.

(3) Lift frames with a batten from sheer, and transfer to half-breadth plan, obtaining expanded frames. Lift spots horizontally from body, and transfer to a half-breadth plan. Now bend a batten through these spots, thus obtaining moulding edge for sheer harpin. To obtain bevelling edge, set down breadth of flanges on body and sheer, as CD. Lift spots as in first case, and transfer to half-breadth, then run bevelling edge as is consistent with fairness, and the distance between the bevelling edge and moulding edge, as EF, gives the amount of bevel.

To lay off a Common Harpin.—(1) Run moulding edge, EF, and bevelling edge, say below moulding edge, on body and sheer.

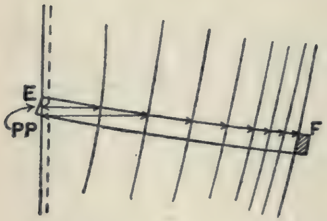


FIG. 117.

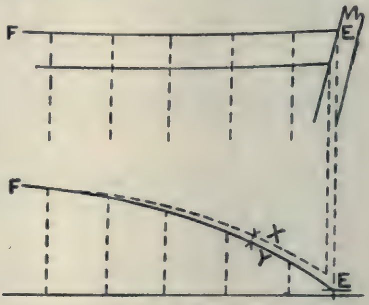


FIG. 118.

(2) Measure girths for moulding edge on body, and transfer to half breadth.

(3) Erect perpendicular PP, and lift breadths of bevelling edge from PP, and transfer to half-breadth plan. Then the distance between the moulding and bevelling edge, as XY, gives the amount of bevel.

Ques. How would you fair the inner bottom edges and longitudinals of a double bottom for a war-vessel?

Ans. **To obtain and fair Outer Longitudinal.**—Having the midship floor all ready on the boards, take breadths at every fifth frame, keeping as square to frames as possible, and draw line, thus obtaining cutting line. Lift breadths horizontally from centre, where longitudinal intersects frames, and lay down on mould-loft floor, thus fairing cutting line. Take mould with run of inner bottom on, and run rest of floors in.

To fair Cutting Line for Top of Floors.—(1) Lift breadths horizontally and transfer to mould-loft floor.

(2) Arrange longitudinals on midships floor, and run them in at each station; then lift the line for both top and bottom edges, and lay down in half-breadth, thus fairing longitudinals.

(3) Arrange plate edges and lift breadths, and transfer to mould-loft floor fairing and correcting them where necessary.

Ques. Describe the methods of laying off stern cants and lifting the bevels.

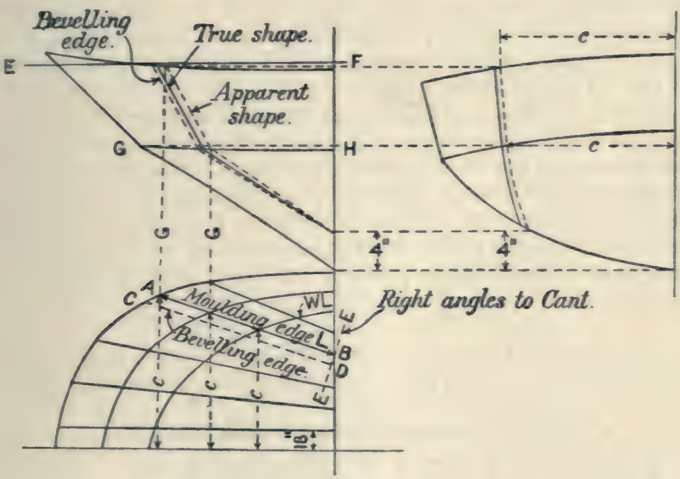


FIG. 119.

Ans. (1) Having the sheer and half-breadths on loft floor, proceed to divide knuckle and rail into same spacing as the frames, marking first frame from centre about 18 inches.

(2) Draw cants on half-breadth, and proceed to lay off cant AB. Run line E at right angles to cant.

(3) Lift breadths C from half-breadth, and transfer to body, and square rail and knuckle up to sheer as G.

To obtain Height of Cant.—Lift height F from body and set off on sheer, and draw cant in, obtaining apparent shape of cant.

To obtain True Shape of Cant.—Lift breadths L from half-breadth, and set off on sheer, and draw line, thus obtaining true shape of cant. Treat remainder of cants in the same manner.

To obtain Bevelling Edge.—Take moulding edge AB on half-breadth, and set the flange of the cant down, say 3 inches, as CD. Now lift rail and knuckle on batten, and set them off on lines EF and GH on sheer, thus obtaining bevelling edge on sheer, and the distance between cant and bevelling edge on sheer gives the amount of bevel, which is generally lifted at five places (see sketch).

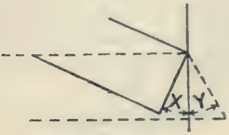


Fig. 120.

Fig. 120 shows the cant notched out to allow for canting. If not notched out, the distances X will form the distance Y, and when canted at right angles to cant; therefore cant AB is cut off at the said bevel.

Ques. Describe the process of laying off ribbands, and state what information is given to shipwrights.

Ans. A lath is bent round the frames to the ribband on body plan. The centre line and every third frame are marked on it; these are then set off their respective frames on the mould-loft floor; a batten $1\frac{1}{2} \times 1\frac{1}{2}$ is bent round these spots, and every frame is marked on the batten and numbered, and also the number of the ribband.

These battens are never long enough (except in very small boats) to reach the whole length of the straight side amidships; therefore two or more are used to make up the length, and made to overlap each other four or five frames, but are not fastened together. These battens are given to shipwright, from which to mark off the ribbands at the ship. The sheer of these ribbands will be nicked on the frames when frames are being adjusted by the frame turner, so that ribbands can be placed in their proper positions when the frame is erected.

Ques. Describe a bow-line, a buttock-line, a water-line, and a square station; and state in which plans these lines appear, and how they appear in each.

Ans. A buttock is a line representing a vertical longitudinal plane parallel to the centre line of a ship. It appears in the sheer plan as a curved line, which represents the true shape of the plane where it cuts the shell of the vessel, and it appears in the half-breadth and body plans as straight lines parallel to the centre line.

A bow-line is simply a continuation of a buttock-line at the fore part of the ship.

A water-line is a horizontal longitudinal section of a vessel, taken parallel to the base line, and is represented in its true shape in the half-breadth plan by curved lines. It is represented in the body and sheer plans by straight lines parallel to the base line.

A square station is a vertical transverse section of a vessel at any point, and is square to the centre line of the ship. It represents the shape of the vessel at that section in the body plan, and is represented in the half-breadth and sheer by straight lines square to the centre line and base lines respectively.

Ques. Make a sketch of a body plan on a scrieve board, showing all the lines put upon it, and stating what each line is for.

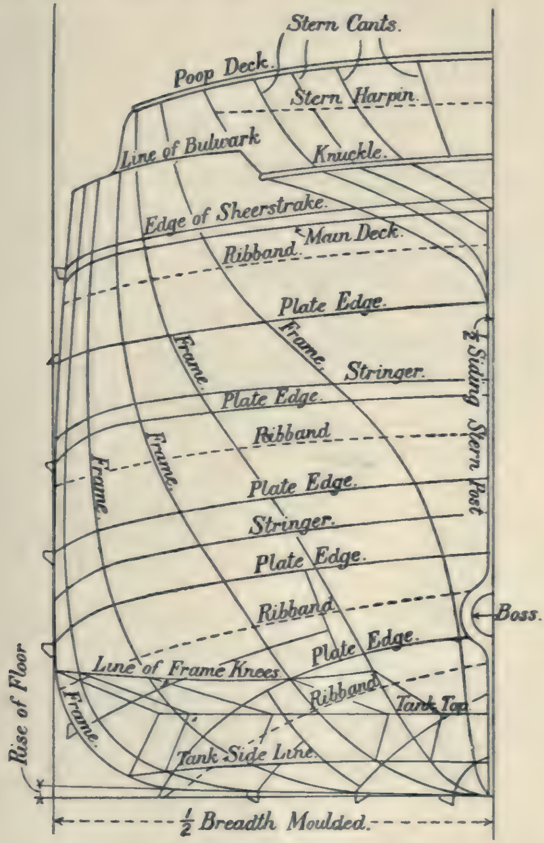


FIG. 121.

Ans. The true shape of each frame is represented, and the lines of all decks, stringers, and sighting edges are also shown run through the spots where they would meet the heels of the frames, and also at the correct heights on stem bar and stern post. The ribband lines are also shown on outside strakes, also the sheer and stem harpins, and knuckle at the after end.

The line of tank top is shown at the proper height, together with the shape of each frame knee outside of the double bottom. The shaded portion on the sketch represents the shape of the floor plate and frame knee at a particular frame. Some strakes, called stealers, are stopped before reaching the stem or stern posts, owing to considerably reduced girths of the ship forward and aft from amidships. The half-sidings of stem and stern post are shown, and also the shape of the propeller shaft boss.

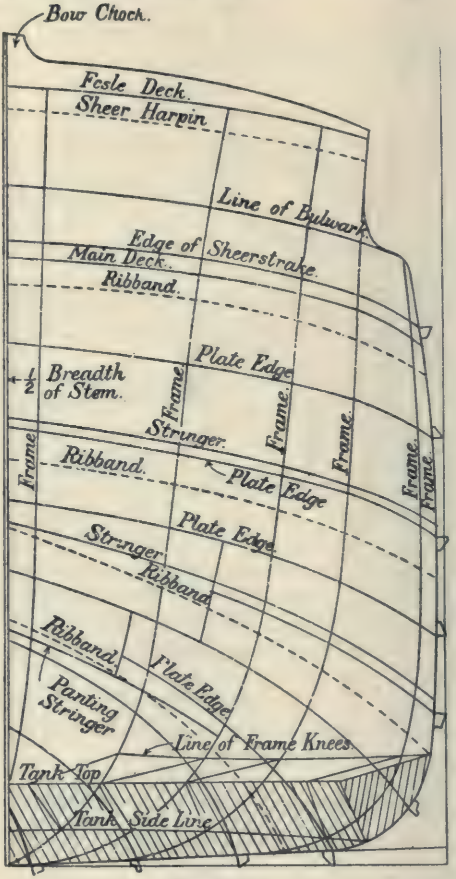


FIG. 122.

The frame lines enable the frame turner to turn the frames to their correct shape. The points where the deck stringers and plate edges meet the frame show where the frame has to be cut, punched for lugs to take stringers, and where to keep the holes to take outside plating clear. By making templates, the correct shape of floor and frame knee can be cut out from the plates. The tank side breadths at each frame enable you to order the tank side plates, and the ribband lines mark the position on each frame at which the ribband must be connected when the frames are up.

Ques. Describe briefly in what order you would proceed to lay down on the mould-loft floor a large-sized steamer, and what moulds you would make, and the order in which you would send these into the yard.

Ans. Strike in a base line on the loft floor, and about the centre of the floor erect a perpendicular to it. Run in a line parallel to the base a distance equal to the depth moulded above it. Also set off on each side of the centre line the half-breadth moulded, and drop perpendicular to the base.

Near each end of the floor draw in the shape of the ship at each respective extremity, and set the sheer forward and aft above the D.M. line. Now set off the frames along base at proper spacing, and erect perpendiculars, setting off sheer heights as supplied from office. Run in sheer line forward and aft to a fair curve. Also set off half-breadths of deck from base line, and run in deck line to a fair curve.

On the body plan set off the corrected half-breadths deck for each frame, and the proper sheer height above the D.M. line. Set off water-lines, buttocks, and diagonals in the body plan, and on them the offsets as supplied from office. Run in frames in chalk, and then fair up in sheer and half-breadth plans, and transfer new offsets to body plan until the whole three agree. Set up heights of stringers, poops, bridge, and forecastle decks, and run in their lines; also set up in body plan height of tank above base, and obtain line of tank side at each frame. Then run in cutting line for tank knees.

Most of the moulds can now be got ready for the yard. The following is a list of the principal moulds, and the order in which they are sent in to the yard :—

1. Flat plate keel.
2. Centre keelson and mould for vertical lugs.
3. Midship floor plate and tank outside knee.
4. Intercostals in tank.
5. Beam moulds and beam knee templates.
6. Stem.
7. Stern and stern club-foot sections.
8. Struts and stern tubes, if twin-screw steamer.
9. Stern cants.
10. Harpins and ribbands.
11. Lugs for connecting longitudinals to frames.
12. Stern expansion and set moulds.
13. Hawse pipes.
14. Boats, beams, and davits.
15. Engine-room skylight, etc., etc.

CHAPTER XII.

SCANTLINGS—LLOYD'S NUMERALS—LLOYD'S AND BRITISH CORPORATION (HISTORICAL)—LLOYD'S TYPES—TESTS FOR MATERIAL.

Scantlings.—The scantlings or sizes of all the different parts of the ship's structure are fixed by the classification society under whose rules the vessel is built. Most vessels are built in this country to Lloyd's rules, although the British Corporation—a comparatively recent society—is getting, by its willingness to consider and assign scantlings for special types of ships, a large proportion of these vessels built to its rules.

Lloyd's.—The term "Lloyd's" is not at all well understood. It is usually regarded as some society for determining the scantlings of vessels, but this is really a small part of its business.

Nearly 400 years ago a Mr. Edward Lloyd had a coffee-house in London, and he catered more especially for shipping gentlemen. As an inducement to these men to patronize his shop, he had agents on the look-out for all arrivals to the port, and round the walls he posted up the latest shipping news. This made the house a rallying-place for shipping agents, and particularly ship insurance agents. Other shops tried to rival him, but greater facilities for doing business and later news of vessels made Lloyd's coffee-house at last the recognized place for doing any insurance business on a vessel. Having got them together, the next thing was to keep them, and a union or bond of insurance agents was formed. This union agreed to have fixed rates and laws for insuring vessels, and progressed so well that ultimately they had a monopoly of the business, and the lists of vessels, arrivals in port, with the description of their main features as made up by Edward Lloyd, became the recognized list, and was called Lloyd's list or Lloyd's register of vessels; and the union that met in the coffee-house naturally became Lloyd's Union of Ship Insurance Agents, or Lloyd's underwriters.

Lloyd's, then, is a vast insurance agency, but it is not one firm. It is still, as at first, merely the house where insurance agents for ships do their business. A person has to be elected a member of Lloyd's, and, after being elected, he can go to Lloyd's buildings and contract business. Now, any insurance agent must have a guarantee on the insured. A life insurance agency will not insure a dying man; a house insurance agency will not insure a timber house if it is alongside a forge. And in the same way Lloyd's must have some guarantee that the vessels they are insuring are seaworthy boats. So they formed a branch committee to draw up certain rules governing the building of vessels. The most common types of vessels in Lloyd's are the two-decker and the three-decker. The dimensions that determine a vessel's size are the length, breadth, depth, and the girth, for obviously one vessel could have a very much finer midship body than another, yet of the same breadth and depth; and as the finer vessel would be really smaller, it would be unfair to ask the same scantlings for it.

Nowadays vessels' midships do not vary very much, but when the rules were made out it was the day of sailing ships, and some midships had coefficients of almost 0·5, so that girth made a material difference, and has never been omitted in subsequent rules. The broader or the deeper a vessel is, the stronger must be her frames and beams and floors; for two vessels with the same length in each case, but the one only half the breadth and half the depth of the other could have lighter beams and frames, etc., so for these parts the length is ignored altogether. The sum of these measurements are called the vessel's numerals, and there are two numerals—the framing numeral and the plating numeral. The framing numeral is the sum of the breadth, depth, and girth, and determines the scantlings of all items which have to resist transverse stresses. The plating numeral is the multiple of the framing numeral and the length of the vessel. It determines the scantlings of all items which have to resist longitudinal stresses.

Lloyd's length is measured at the freeboard deck from the after side of the stem to the fore side of the stern-post.

Lloyd's breadth is the greatest moulded breadth. Lloyd's allow for every foot of breadth the beam to be raised $\frac{1}{4}$ inch, so that in a vessel 40 feet broad the beam at the middle of its length would have a rise up, or camber or crop, of 10 inches.

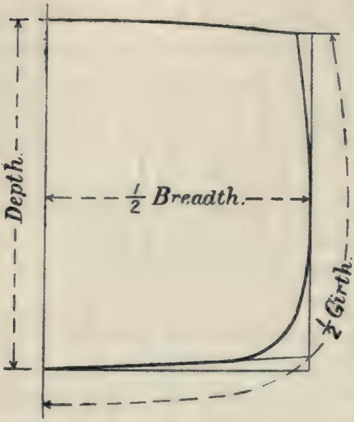


FIG. 123

Lloyd's depth is measured at the middle of the beam's length to the top of the keel. **Lloyd's half-girth** is measured from the beam at side to the top of keel round the line of frame.

Lloyd's Numerals.—Framing numeral for a two-decker = half-breadth + half-girth + depth.

Plating numeral = framing numeral × length.

For a three-deck ship the numerals are as above, but a deduction of 7 feet is allowed from the framing numeral.

For spar and awning deckers the freeboard deck is taken as the main deck.

Lloyd's rules are recognized by all shipbrokers and owners as producing a thoroughly sound and reliable ship. They have been, however, so long in use that the present rules are very different from those originally issued. When a vessel showed any signs of weakness, that part was strengthened by making the structure stouter. The rules, then, are very largely empirical; they are the result of practical experience with ships, and while it is granted that these vessels are stout, seaworthy boats, it is also affirmed that they can be made quite as strong with less weight of metal at some parts. Every ton of steel saved in construction is a ton gained in dead weight, and consequently a gain in money-making power, and all the skill, science, and finessing of shipbrokers, owners, and builders resolve themselves eventually into the financial problem.

The British Corporation Society's rules have been founded on the latest scientific knowledge. The ship was treated as a girder, and the scantlings required for the various parts were directly calculated. Afterwards these scantlings were compared with other rules, and where a large difference existed the cause of this difference was looked into, and British Corporation scantlings were modified if necessary. The saving at first over Lloyd's was nearly 10 tons in every 100, but subsequent additions found necessary by actual working of ships at sea reduced this margin until now the difference is only about half this. But the great feature of the British Corporation is that they will class any kind of vessel—trunk, turret, whale back, single deck, or any other that the ingenuity of the naval architect can produce.

The British Corporation will assign a freeboard for any class of vessel provided they consider it strong enough to withstand the strains it is likely to encounter. As they are a later company and dealing only with present-day vessels, the girth measurement is ignored entirely, and the rules are founded on length, breadth, and depth.

Lloyd's Types.—Lloyd's have quite a number of different kinds of vessels, and the reason for this is as follows. All vessels do not trade between same ports and carry same cargoes. Some vessels are tramp steamers, and must be able to carry any cargo. And here it will be as well to note that the science of shipbuilding has to do about 90 per cent. with cargo-carrying vessels. Boats are built to carry. Passenger boats are a very small percentage of the world's merchant navy. The tramp steamer, then, must go anywhere and carry any cargo. One vessel might have a light cargo, such as cotton, or a heavy cargo, such as coal. That vessel has only a certain fixed cubic capacity. If it takes, say, 126 cubic feet to stow 1 ton of cotton, and only 42 cubic feet to stow 1 ton of coal, the ship will only be able to carry one-third the weight of cotton that it would of coal. And if it was always in one trade, carrying cotton, it would not be at so great a draught load as if always carrying coal. The more weight a vessel is carrying the greater will be the working of the structure, and the heavier and consequently stronger that structure will have to be.

Here are two vessels identically alike in dimension, yet the one is carrying three times as much as the other. If we make the scantlings strong enough for the coal-carrying boat, they will manifestly be too strong for the cotton-carrying boat; and if we make them to suit the cotton boat, they will be too light for the heavy strains which the coal boat would have to endure.

What is done is to assign each vessel a class of its own and fix the draught of each, for the draught, of course, that the vessel can load to determines the weight of the cargo carried. The cotton boat, even when full up, will have a very light draught because of the lightness of the cargo. Then make the load draught of the ship to suit the cargo, and if it cannot load deeper or take a heavier cargo, it will never experience heavier strains. The coal boat, when full, will sink very deep in the water because of the heavy cargo; then fix the load line at that deep draught, but make the scantlings much heavier, so that they will be able to resist the heavy strains due to the greater weight carried, equally as well as the other was able to resist the lighter strains. This is the reason of the different classes.

Always note that, although the scantlings are lighter, the vessel is just as strong when loaded, because when the load draught is lighter the cargo carried is less, and of course the strains experienced are not so great, and lighter scantlings are able to resist them. Of the same class, but different only because of size, are—

1. The one-deck class;
2. The two-deck class;
3. The three-deck class.

These all get the deepest draught allowed. Other classes in the order of their draughts are—

The spar decker;
The awning decker;
The shelter or shade decker.

The shelter decker gets the least draught for the size of vessel. The well decker is merely an abortive type of the one- or two-decker class, and is useful for tonnage purposes.

Tests for Material and Water-tight Work.—The reason for testing material to be used in a vessel's construction is obvious. The standard of the test is not so obvious.

Wood by observation alone could be passed or condemned. The shipwright saw at once whether or not a plank was fit to be used for a ship's sheathing. But as iron superseded wood the necessity of a mechanical test soon became manifest. You could not tell by looking at a piece of iron whether it was "tough" enough for shipbuilding. Some test had to be made, and the necessity of a test also made necessary a "standard toughness" of material.

What happens to, say, a shell plate during its life after leaving the manufacturer? It is cut in the yard, punched there, and bent there. On the ship it meets the blows of the sea, it meets forces tending to crush it, and forces tending to pull it apart. To resist all these stresses a plate must be very tough. A plate of lead would be splendid for cutting and punching and bending, but useless for resisting crushing or stretching stresses. In the same way nickel steel or chilled steel might be splendid for resisting crushing or stretching stresses, but would be useless for cutting into shape or punching or bending cold, as it would immediately break. It is the mean of these two extremes that is wanted.

The unit of area employed for testing is 1 square inch. A strip is taken 1 square inch in section and 8 inches long. This is called the test piece, and one or more of these is taken off every mould made in the steel works, the metal being run into a mould and then rolled through rollers to its required thickness. There may be enough material in the mould to make a dozen shell plates, but as it is presumably all the same strength, each separate plate does not require testing. One of the test pieces from this mould 8 inches long 1 inch square in section undergoes a test the equivalent of having a weight of 30 tons suspended from it. What is really done is that it is gripped on a table at each end by the jaws of the testing machine, and the force of 30 tons is exerted to pull it asunder. The piece must be hard enough to resist breaking, and it must be soft enough to stretch about 1½ inch, but hard enough to stretch no more. It would be, however, unfair to have a hard-and-fast rule of 30 tons, so Lloyd's allow a margin of 2 tons either way. The British Corporation allow 2 tons under and 3 tons over. This gives the makers a certain reasonable latitude. The piece is also bent and straightened to test its fibre. Another piece is heated to a low cherry-red and then plunged into water of 82° F. This makes it very hard. In this condition it must bend round a half-circle, the diameter of which equals three times the thickness of the strip. The stretching test is called the tensile stress, and a summary is made of it as follows:—

Lloyd's steel plates must have a tensile strength of 28–32 tons, with an elongation of 20 per cent. on 8 inches for plates $\frac{8}{20}$ inch thick and over, and 16 per cent. for plates under $\frac{8}{20}$ inch thick. Plates which are specially marked to undergo during construction cold flanging, etc., may have a tensile strength of 26 tons. (This means they are so much softer.) Steel angles, bulbs, channels, etc., may have a tensile stress of 33 tons. (This is an additional ton of margin for these sections.)

British Corporation.—Tensile strength of iron, 18–22 tons. Steel, 28–32 or 33, with an elongation of 16 per cent. on 8 inches. Plates for cold flanging, 25–29 tensile strength. Temper strength as Lloyd's. Rivets, 25–30 and 20 per cent. elongation.

Castings.—Lloyd's, 28–35 tensile, with at least 8 per cent. elongation on 8 inches. Strips, 8 inches × 1 inch × 1 inch to bend cold through 90°. Stern frame to be dropped on ground from 45°, or if in two pieces from 7–10 feet of a drop. It is also slung up in chains and well hammered with a 7-lb. hammer.

British Corporation castings, 6–10 feet are dropped through 90°. Tensile, 26–35.

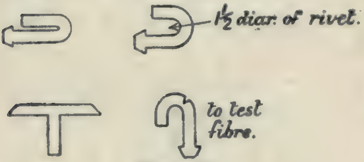


Fig. 124.

Rivets when hot must be able to bend double.

Rivets when cold must bend round a circle 1½ diameter of rivet.

Head flattened out to 2½ diameter of rivet.

Edges to be nicked and bent round to test the fibre.

The material of rivets is of special quality, soft and ductile. Lloyd's test for iron, 20 tons with and 18 across the grain.

Note that iron has a distinct fibre. Steel is more amorphous or granular.

Admiralty Tests.—Iron, 22 with and 18 across the grain. Steel, 26–30, 20 per cent. on 8 inches, etc., as Lloyd's. Rivets, as Lloyd's. Cast steel, 26 tons tensile, and 10 per cent. elongation on 8 inches. To bend cold, 45°.

The tests for water-tight work are as follows:—

Bulkhead testing, fore peak filled to load water-line.

„ „ aft „ „ „ „

Other bulkheads are tested with a hose.

Upper and weather decks, with a hose.

Gutterways to be flooded.

Double bottom head of water = extreme draught.

Deep tank „ „ = 8 feet above crown.

Fore-and-aft peak tanks 8 feet above crown, but never less than extreme draught.

CHAPTER XIII.

LLOYD'S RULES AND BRITISH CORPORATION RULES FOR STEEL VESSELS.

LLOYD'S RULES.

Class.—A vessel will be classed "A" provided it is found to be in a fit and efficient condition for its contemplated employment. For any particular trade an affix, such as "A" Fishing smack, "A" For tug purposes, etc., will be given.

The number prefixing the letter is 100 if the vessel is built in accordance with the rules. Vessels not up to 100 in construction may be 90 or 95. If the equipment, that is, the anchors, chains, cables, hawsers, etc., is as required by the tables, the figure 1 is placed after the character assigned to the vessel. Thus if a vessel is built to Lloyd's rules for hull and equipment, she will be classed 100 A1, and if built under special survey, 100 A1*.

Scantling numbers are as already shown in Chapter XII.

Stem, stern-post, and keel scantlings are regulated by the second or plating numeral, and, where they are scarfed together, the length of scarf to be nine times the thickness, with the holes in the thin end drilled and not punched.

Butt straps of flat plate keels are treble riveted. The stem at the deck need only be three-fourths of the thickness under water.

The proportions allowed in framing the rules are up to eleven depths to the length, that is, a vessel 11 feet deep should be no longer than 121 feet, and a vessel of, say, 363 feet in length, should be at least 33 feet deep. Most large vessels have not these proportions, and a table is given of the additional strengthening required.

Frames extend in all cases from the keel to the gunwale, and must fit closely on the keel. In very full steamers forward the frames for three-fifths length from the stem are doubled from bilge to bilge. Scantlings may be reduced for one-fifth length from both ends. A frame eight-twentieths thick amidships need only be seven-twentieths thick at the ends.

The spacing of frames may be from 20 inches to 27 inches, according to the size of the vessel.

Floor plates have their thickness and depth at centre determined from the framing number. The midship scantling, as in the frames, only extends for three-fifths of the vessel's length amidships. At the ends the thickness may be reduced.

Reverse frames are fitted on every floor, and in small vessels extend only from bilge to bilge. In other vessels the reverses extend alternately to the upper deck and top of stringer bar next below it. Thus reverse on, say, frame 60, would go to upper deck; on frame 61, to stringer below; on frame 62, to upper; on 63, to stringer below; and so on. In awning deckers they all extend to main deck. In engine and boiler spaces double reverses are fitted. In aft peak in vessels of about 300 feet and over, all reverses extend to the upper deck. In forecastles reverses extend alternately to forecastle and main decks.

Middle-line keelsons may be fitted on top of floors fore and aft, or they may be intercostally fitted between floors, or they may consist of a continuous fore-and-aft girder with the floors butting against it on either side.

Keelsons and Stringers.—All vessels must have a bilge keelson fitted at the lower turn of bilge, and extending all fore and aft. Other keelsons required in the hold depend entirely on the size of the vessel. Keelsons and stringers must extend as far forward and aft as practicable.

Beams may be fitted on every frame or on alternate frames. In the latter case they should take the frame with the reverse carried up, and beams of one deck should be over beams of deck below. Beams at hatch ends are made heavier. Beams under a water-tight flat are fitted on every frame. Beam knees are two and a half times the depth of beam, and across the throat six-tenths depth of knee.

In vessels with only one tier of beams, in the lower deck of vessels having deep framing, in beams of water-tight flats, in beams supported by three pillars, and in beams of sailing vessels, the knees require to be three times the depth of the beam. Vessels up to 15 feet 6 inches depth require only one row of beams. For about every additional 7 feet of depth an additional row of beams is required.

Web frames may be fitted in lieu of hold beams, and by this means a clearer hold space is secured. The depths of the webs vary from 14 inches to 18 inches, and the distance between webs from eight frame spaces to four frame spaces. Thus a vessel of 16 feet depth requires hold beams. To dispense with these, 14-inch web frames eight frame spaces apart may be fitted. In vessels of 23 feet depth, 16-inch webs six frames apart are fitted in lieu of hold beams.

Deep frames are introduced in lieu of hold beams, and give even a freer hold for cargo than the web frames. All frames are made deeper, but the ordinary reverse is fitted. A vessel fitted with hold beams would have, say, 5-inch frames. With the hold beams dispensed, the framing would be 7½ inches deep in double-bottomed ships, and 8 inches in single-bottomed ships. With deep framing heavier side stringers are fitted. Beam knees of lower tier of beams are three times the depth of beams.

Pillars.—The diameter of pillars depend on the breadth of ship and depth of hold. Where the beam is 43 feet and under, it is supported by one row of pillars fitted along the centre line. Over 43 feet and under 55 feet, two rows of pillars are fitted. Over 55 feet three rows are fitted. Pillars are fitted every alternate frame space. If beams are on every frame, the pillars will be only supporting one beam, and the other will be unsupported. To help this, continuous fore-and-afters are run under the beams, and the pillars are attached to these, thus distributing the support over all the beams. Where beams are on alternate frames, each pillar will catch a beam, and no fore-and-after is required.

Decks.—In all vessels stringers and tie plates are required on every tier of beams. Where a wood deck is laid, the timber should weather for about 6 months after cutting, so that it will be properly seasoned before fitting. The thickness of planking is obtained from the tables, and varies from 3 inches to 4 inches, the securing bolts varying from ½ inch to ⅝ inch. There must be a bolt through each plank and each beam, and where the plank is over 6 inches broad it must be secured by two bolts to every beam.

Steel decks are required to be fitted to vessels according to their plating number, and their proportion of depth to length. Thus, a vessel whose plating number is, say, 20,000, and is under ten depths to length, requires no steel deck; whereas with the same plating number, but over fifteen depths to length, two complete steel decks are required. The midship thickness of plating extends for half the length of the ship. At the ends plating may be reduced.

Steel decks may be fitted over beams on alternate frames, except where Lloyd's consider that they are too thin to resist buckling between the beams. The limit is fixed at eight-twentieths, and decks below this thickness must have beams on every frame. Of course, if a wood deck is fitted, there will be little tendency to buckling, and beams may be on alternate frames, however thin the plating is. Where a wood deck is fitted on a steel deck, the thickness of the wood deck may be reduced one-fourth. Thus a 4-inch wood deck required, need only be 3 inches when laid on a steel deck.

Outside Plating.—The thickness of the shell plating is determined from the plating numeral. The midship thickness is maintained for half the vessel's length amidships, beyond which it may be gradually tapered to the thickness required for the ends. In steamers with full forward ends, two strakes of bottom plating have their midship thickness maintained right forward to the collision bulkhead. Where two thicknesses are given for shell plating, the outer strakes have the greater thickness. Plates, except at ends, must be at least six frame spaces long, and have their butts so arranged that in adjoining strakes they shall not be nearer than two frame spaces, and in alternate strakes they will not be under each other, but shifted at least one frame space clear. Outside strakes must not exceed 46 inches in breadth, and inside strakes 54 inches.

Riveting.—Sheer strakes, stringers, and one strake of bilge plating have double-riveted butt straps in all vessels up to, say, 150 feet long. Vessels about 250 feet in length have their sheer strake, stringers, bilge plating, and all outside strakes treble riveted. Vessels about 400 feet long and upwards have all their plating butts treble riveted. Flat-plate keels have treble-riveted butt straps, or laps. All butt straps are $\frac{1}{20}$ inch thicker than the plates they connect. The outer strakes of shell plating are countersunk, in order to give the rivet a better hold, the heads being all flush with the plating.

All double and treble riveting to be chain riveted, except attachment of stem and stern-posts. All bulkhead riveting may be single, except connection of floor to bulkhead, where double-riveted seams must be fitted. Edges of outside plating are single or double riveted, according to thickness. In vessels of 480 feet in length and upwards, certain landings forward and aft require treble riveting.

Water-tight Bulkheads.—Water-tight bulkheads extend to the freeboard deck. Sailing ships only require one bulkhead to be fitted a twentieth of the vessel's length abaft stem, and called the "collision bulkhead." Screw steamers with machinery amidships require a collision bulkhead, a bulkhead at fore and after ends of machinery spaces, and an after-peak bulkhead a reasonable distance from the stern-post. If the vessel is over 280 feet and under 330 feet, an additional bulkhead is to be fitted in the fore hold, and in general every 70 feet of additional length above 330 feet requires an additional water-tight bulkhead. Thus a vessel 540 feet would have eight water-tight bulkheads. Bulkheads are connected to the shell by double frames. In way of outside strakes, doubling plates are fitted to catch a frame on each side of the bulkhead.

Bulkheads are stiffened vertically on one side and horizontally on the other. Vertical stiffeners are same size as main frames, spaced not more than 30 inches apart, and bracketed to tank top. Horizontal stiffeners are spaced not more than 48 inches apart. Additional vertical stiffening by means of deep web plates is required in large vessels.

Double Bottoms.—Man-holes to enable the inner surface to be examined are required to be fitted. All water-tight joints are to be made so, without the use of felt, canvas, or other packing.

The upper side of tank plating must be protected by 2½-inch ceiling laid on 1½-inch sleepers, or bedded in cement tar. Where girders are fitted on top of ordinary floors, they must not be more than 3 feet apart. In vessels having a full forward body, the frames for three-fifths length to collision bulkhead are to be doubled. When double bottoms are fitted, the outside shell plating in way of the double bottom may be reduced one-twentieth in thickness when it is eleven-twentieths or over. Keel-plate and garboard strakes are not reduced. The bracket plates are connected to the margin plate by double angles, and in large vessels a fore-and-aft gusset plate is to be fitted connecting top of bracket plate and tank top.

Both flanges of the frame inside tank may be the same size. (This means that if the ordinary frame outside the tank is $5 \times 3 \times \frac{8}{20}$, inside the tank it may be $3 \times 3 \times \frac{8}{20}$.)

Inner bottom plating must run fore and aft. The middle strake to have double-riveted butts and edges all fore and aft. Vessels about 300 feet long have their tank-top butts double riveted for half-length, and in large steamers the butts all fore and aft, and the edges for half-length, are double riveted. Rivets in butts and edges are not to be more than four diameters apart.

The centre girder must not be cut for man-holes. The bulkheads are connected to the tank top by double angles. In vessels of full form forward, the two strakes of outside plating next the garboards to have the midship thickness maintained forward to the collision bulkhead. In double bottoms, where the breadth from margin plate to margin plate is under 34 feet, only one intercostal a side is required. From 34 feet to 44 feet, two intercostals a side are required.

Three-deck Steam Vessels.—Three-deck steamers must not be less than 17 feet deep. The framing number is taken to the upper deck, and 7 feet deducted. All frames extend to the upper deck.

Reverses extend alternately to the upper and to the top of the middle-deck stringer angle.

Sheer strake is placed at the gunwale.

Spar-deck steam vessels are of lighter construction and less draught than three-deckers. They must not be less than 17 feet deep. The framing number is taken to main deck. All frames extend to spar deck. Reverses extend to main and spar decks alternately. The sheer strake is fitted at the main deck. The measurement of depth for any additional scantling required for proportions is taken to main deck.

Awning-deck steam vessels have their main structure to the main deck, and above this is built a light continuous superstructure all fore and aft. The framing number is taken to the main deck. Frames extend to awning deck. Reverses extend to main deck. Sheer strake is fitted at main deck.

Poop, Bridge, and Forecastle.—All main frames extend to the top of the erections. Bulkheads at fore end of bridge and poop have bulb-iron stiffeners spaced 30 inches apart and bracketed top and bottom. The sheer strake at the breaks of the erections is doubled. In forecastles the alternate reverses extend to the forecastle deck.

Raised Quarter Decks.—All main frames and alternate reverses extend to quarter deck. Sheer strake is to be doubled at the break. Main-deck stringer and quarter-deck stringer overlap at the break eleven frame spaces. The deck plating is scarfed four frame spaces or five frame spaces, according to size of vessel.

Extreme Proportions.—Lloyd's rules are framed for vessels whose length does not exceed eleven times their depth. Where this proportion is exceeded, additional strengthening is required. All vessels over sixteen depths to length must be specially considered by the committee.

BRITISH CORPORATION RULES.

Classification.—Vessels are classed B.S.* if built to British Corporation rules, and under special survey during construction. If not built under survey during construction, they may be classed B.S.

Dimensions.—Length is measured at the load-line from the fore side of stem to the after side of post.

Breadth is greatest moulded breadth over frames.

Depth is the moulded depth from top of keel to top of upper-deck beam at side measured at middle of vessel's length on load-line.

The rules are framed to suit vessels having the length not more than fourteen times the depth. Beyond this limit vessels will be specially considered.

Decks.—The weather deck in all cases is called the upper deck; the deck below is the second deck, and the next the third deck, and so on.

Scantlings.—Items of longitudinal strength have their scantlings determined by length in conjunction with either breadth or depth. Items of transverse strength have their scantlings determined by length or breadth, or both combined. No numerals are used. The dimensions alone determine the scantlings. For example, a vessel 400 feet long requires twenty-five-fortieths of shell plating. Scantlings are given in fortieths, and not twentieths, as in Lloyd's.

Keels.—Bar keels are to be forged in long lengths, and scarphed or welded together. Rivet-holes in thin end of scarph are to be drilled after keel is laid on blocks.

Centre girders are continuous in vessels over 300 feet, and are connected to floor plates by double angles. Flat-plate keel is connected to centre girder by two continuous angles all fore and aft. Flat-plate keel should be fitted on outside strake.

Stem and Stern-post.—The stem at the deck need only be 70 per cent. of the tabular breadth. The stern-post at the head may be 75 per cent. of tabular size. The heel of the post must extend into the ship's structure three to four and a half frame spaces. In screw steamers the outer post may be 15 per cent. less than tabular size, and at head 50 per cent less than tabular size. Transom floors to take the stern-post are one and a half times the depth of midship floors.

Frames.—The thickness amidships is maintained for three-fifths length. Beyond this a reduction is allowed. All frames extend to upper deck, or to poop, bridge, or forecastle. Bulkhead liners need only be two frames in width, that is, if frames are 3 inches, the breadth of the liner will be 6 inches. In vessels over 15 feet depth, the reverses extend alternately to upper and second decks, alternately to forecastle, all to upper deck in aft peak. In steamers 375 feet long all reverses extend to upper deck in machinery spaces.

Frame spacing for about one-tenth of vessel's length from each end must not exceed 24 inches. Frame spacing amidships varies from 20 inches in vessels of 8 feet depth, to 29 inches in vessels of 44 feet depth.

Floor plates are fitted on every frame. Midship thickness is maintained for half-length. Beyond this the thickness may be reduced. Floor plates at the lower turn of bilge must not be less than half their midship depth, and extend up the bilge for a height not less than twice their midship depth.

Beams.—Where beams are fitted on alternate frames, they must take the frame on which the reverse extends to the upper deck. Where thin steel decks are fitted and no wood deck laid, beams must be fitted on every frame; and also where the deck forms the crown of a deep ballast tank, beams are on every frame. Beam knees are one-twentieth thicker than the beam.

Web Frames and Deep Frames.—The lower tier of beams may be dispensed with by fitting web frames or deep frames.

A table gives scantlings and spacing of the webs, and also depth of deep frames. The beams at the head of the web frame are 1½ inch deeper than the ordinary beam in two-decked vessels.

In three-deckers the beam to take the web frame requires to be made up of a deep plate and four angles.

In deep-framed vessels the beams of the lowest fitted deck must be of scantlings, which would have been required for the omitted deck.

Pillars.—Pillars may be either solid or tubular, but if the latter they must have solid welded heads and heels. The ends must be secured by at least two rivets, and, where double bottoms are fitted, must not be connected directly to tank top, but to short tee-pieces riveted to tank. Vessels under 43 feet beam only require a centre row of pillars. Between 43 and 55 feet beam two rows are required. Over 55 feet beam three rows are required. Stanchions are spaced two frame spaces apart, except at ends, where they may be four frame spaces apart. Double stanchions, fitted to take grain boards, may be each one-fourth less than required for a single row. Wide-spaced pillars will be approved of if associated with suitable fore-and-aft girders under beams.

Keelsons and hold stringers must have a shell connection, except those running on top of floors. Centre keelsons, if fitted above ordinary floors, must have rider and foundation plates and double angles top and bottom. The rider plate extends for three-fourths length, and the foundation plate two-thirds length. Where keelsons and stringers are cut at bulkheads, substantial brackets, with double-angle connections on each side, are to be fitted.

Beam Stringers and Ties.—Side stringers must be fitted on all tiers of beams, and maintain their midship breadth and scantling for half-length, when they may be gradually tapered at the ends. When any holes have to be cut in the stringer, suitable compensation must be provided. In way of erections, a continuous stringer angle is worked along the face of frames, and connected to the frame by short lug pieces. Shell chocks are also fitted between frames connecting stringer to shell. Tie plates are fitted on each side of hatchways, and continued all fore and aft. Diagonal tie plates are also fitted for about three-fourths length amidships.

Panting Arrangements.—End floors are considerably deepened. Hold stringers and keelsons at ends must not be more than 6 feet apart, and have breast hooks fitted. Panting beams to be fitted at keelsons as desired.

Shell Plating.—Where two thicknesses of shell plating are required, the greater thickness is to apply to the outer strakes. The midship thickness is maintained for half-length, and gradually reduced to ends. The garboard strake maintains the midship thickness all fore and aft. Outside strakes should not exceed 46 inches in width, and inside strakes 52 inches, but with extra long plates these widths are proportionately increased. No plate to be less than six frame spaces in length, except at ends of vessel. No butts of adjacent strakes are to be nearer each other than two frame spaces. Where holes for scuppers, side lights, coal shoots, etc., are cut in plating, they must be efficiently compensated for, and special care must be taken to maintain the continuity of strength at breaks of erections.

Water-tight Bulkheads.—All water-tight bulkheads required by the rules extend to the freeboard deck. The vertical stiffeners are to be spaced not more than 30 inches apart, and bracketed top and bottom in lower 'tween decks and holds. Bulkheads are connected to the shell and tank top by double angles. Collision bulkheads are fitted not less than one-twentieth of the vessel's length from the stem, and no openings will be permitted in this bulkhead without special sanction of the committee. All steamers to have aft-peak bulkheads, and also bulkheads at each end of machinery space. Other bulkheads are fitted according to vessel's length, but the rules provide for no more than six bulkheads.

Decks and Ceiling.—Wood decks must be laid on upper-deck beams, except where steel or iron decks are fitted. The thickness varies from 3 inches to 4 inches. Where steel decks are fitted in conjunction with wood decks, the thickness of sheathing may be one-fourth less than required by rules.

Thus if a wood deck is required to be 4 inches thick, when fitted on a steel deck it may be one-fourth less, or 3 inches thick. Pitch-pine planks must not be more than 5 inches wide. Yellow pine or teak may be 6 inches wide. Margin planks of weather decks should be teak or greenheart. Steel decks, when unsheathed, may have beams on alternate frames if the thickness of deck plating is in accordance with table. When thinner deck plating is fitted, and deck not sheathed, beams must be fitted on every frame.

Compensation must be provided on decks where large openings such as hatchways are cut, in accordance with a scheme of compensation which the British Corporation have devised. Thus it would state on the midship section that compensation was based on thirteen-fortieths, with 20 per cent. opening. This is in wells. Assume the vessel to be 50 feet beam, the British Corporation allow an opening 20 per cent., or 10 feet wide, and the deck between opening and stringer may be thirteen-fortieths thick. If the opening is wider than 10 feet, the sectional area lost through the excessive opening must be compensated for on strakes alongside opening.

Water-ballast tanks should be divided approximately to coincide with water-tight bulkheads. Cellular double bottoms may have solid floors on every frame or on alternate frames, with intermediate bracket floors, and fitted in conjunction with fore-and-aft girders. In deep tanks a central bulkhead must be fitted for full depth. In vessels of 360 feet and over, gusset plates are fitted to connect bracket plate outside tank to margin plate. The shell plating in way of the double bottom, except the garboard and keel plates, may be reduced one-fortieth or two-fortieths, according to size of vessel. Under engines and boilers special strengthening is required, and is generally obtained by introducing additional fore-and-aft intercostals, and thickening the floors, tank top, etc.

Suitable and sufficient man-holes, having steel or wrought-iron covers, must be provided to give free ventilation and ready access to all parts of double bottom.

Rivets.—Steel rivets are recommended for steel work. Rivets connecting different thicknesses together are to be of the diameter required for the greater thickness, except where the difference is excessive. Rivet-holes are to be punched from the faying surfaces. Rivets for shell and water-tight work must be swelled in the neck to efficiently fill the countersink caused by punching.

Centre-plate riveting is	4½	diameters	centre to	centre.
Frames, floors, beams, etc.,	7	”	”	”
Double-bottom water-tight work,	4½	”	”	”

Bulkhead plating,	4½	diameters	centre to	centre.
„ stiffeners,	8	„	„	„
Shell plating,	3½–4½	„	„	„

Finally.—Items not noted are in general very similar to Lloyd's requirements.

Questions on Chapter XIII.

Ques. What are the requirements of Lloyd's, British Corporation, Bureau Veritas, as regards water-tight subdivision? What consideration usually fixes subdivision of cargo steamers?

Ans. Lloyd's rules provide that all ships should have a collision bulkhead fitted not less than half the midship breadth from stem, or five per cent. of the length. *Lloyd's rules provide* that all steam vessels should have four water-tight bulkheads, namely, collision bulkhead, after-peak bulkhead, and two bulkheads encasing engines and boilers; but owing to sometimes having such very long fore-and-after holds, that, were one of them to become damaged, and the sea to enter, the loss of buoyancy or floating power would be so great that sinking would be inevitable, therefore Lloyd's provide that all steam vessels 280 feet long and above require five bulkheads, the extra bulkhead being fitted in fore hold; also that steam vessels 330 feet long and above require six bulkheads, the extra bulkhead being fitted in after hold. Bulkheads extend to freeboard deck in vessels of two, three, spar and awning deck classes, except the collision bulkhead, which is extended to weather deck in all classes.

In sailing ships collision bulkhead is only required.

British Corporation rules provide that all ships should have a collision bulkhead, fitted not less than five per cent. of the vessel's length from stem.

Steam Vessels.—British Corporation rules provide that all steam vessels should have four water-tight bulkheads, namely, collision bulkheads, after-peak bulkhead, and two encasing engines and boilers; but owing to excessive length of holds, the British Corporation rules provide that vessels 280 feet long and above require five bulkheads, the extra bulkhead to be fitted in fore hold; also that steam vessels 330 feet long and above require six bulkheads, the extra bulkhead to be in after hold, and fitted at least one-fourth of the vessel's length from post. In sailing ships collision bulkhead only is required but if pumps are used at after end, after-peak bulkhead will be required.

Bureau Veritas provide that all vessels should have a collision bulkhead fitted not less than four per cent. of the vessel's length + 7 feet from stem.

Steam Vessels.—Bureau Veritas rules provide that all steam vessels should have four bulkheads, namely, collision, after-peak, two encasing engines and boilers; but where holds exceed 90 feet, intermediate bulkheads are fitted.

Sailing Ships.—Bureau Veritas rules provide that sailing ships should have a collision bulkhead fitted; but if the vessel is 250 feet long and above, they advise one centre bulkhead about midships, also in vessels 300 feet and above, they advise two centre bulkheads.

Considerations of Merchant Steamers for Water-tight Subdivision.—Bureau

Veritas recommend (1) that cargo steamers should remain afloat with any one compartment filled, but this rule is not enforced, owing to giving way to stowage. Longitudinal bulkhead fitted in holds totally dispensed with, owing to same cause. (2) That the bulkheads be so arranged that the alteration in trim would not be too excessive when any compartment is in free communication with the sea. (3) Bulkheads should be extended up to the upper deck in three-deck vessels, upper deck in upper-deck vessels, and main deck in awning-deck vessels, except collision bulkhead, which is extended up to awning deck.

Note.—B.V. rules are specially designed to suit the requirements of oil-carrying steamers.

Ques. What are the principles which should regulate the number, height, and strength respectively of the transverse water-tight bulkheads in ships?

Ans. The number of bulkheads in a ship is regulated by considerations of safety and the length of the ship. There should be in all steam vessels a bulkhead at each end of the engine and boiler space, so as to divide the engine and boiler from the remainder of the vessel, in case of either of the holds at each end being bilged, or in case of the engine and boiler rooms being bilged; for protection of engines, and also to keep the heat, as far as possible, from affecting the air in the holds. There should be a bulkhead some distance from the stern-post and one aft of the stem; the former to collect all the leakage from the stern tubes, and also to form a water-ballast tank for trimming purposes; the latter to collect any leakage due to panting at the bows, and also to confine any damage done forward of this bulkhead in collision to this part. This bulkhead is called the collision bulkhead. The remainder of the transverse water-tight bulkheads should be so placed as to localize any damage, and if possible to prevent the vessel from sinking if any of these compartments are bilged.

The number of bulkheads vary according to class of ship. In battle-ships and cruisers there are a great many bulkheads, as, when in action, a good many of the water-tight compartments might be filled, owing to the outer skin being pierced by shot, torpedo, or rammed. In passenger ships, to ensure greater security, very often the number of bulkheads is such that if in moderately fine weather any two compartments were bilged, the vessel would still remain afloat and navigable. In merchant ships, however, owing to the requirements of particular trades and stowing of cargo, there are generally just the bare number of bulkheads required by the classification society. In 1890 "The Bulkhead Committee," which sat in the House of Commons, made a number of suggestions regarding bulkheads in mercantile steam vessels, dividing the ships into six grades.

1st Grade (Highest).—First-class passenger ships and cross-Channel ships should float in moderate weather with any two compartments flooded.

2nd Grade.—Passenger steamers from 425 feet to 350 feet in length should float with any two of the forward compartments flooded, or any one after compartment (in moderate weather).

3rd Grade.—Passenger steamers from 350 feet to 200 feet long should float in moderate weather with any two of the forward or any one other compartment flooded.

4th Grade.—Passenger ships under 300 feet in length, and sailing ships carrying more than one passenger per 33 tons register, should float in moderate weather with the two foremost or any one compartment flooded.

5th Grade.—Cargo steamers over 300 feet in length, and sailing ships over 275 feet long, should float in moderate weather with any one compartment flooded.

6th Grade.—Cargo steamers less than 300 feet, and sailing ships less than 275 feet in length, should float in moderate weather with any one compartment in fore body flooded.

Lloyd's Requirements.—

Vessels under 280 feet long should have 4 bulkheads.
" 280–330 " " 1 extra bulkhead in fore hold.
" 330–400 " " 1 " " in each hold.
" 400–470 " " 7 bulkheads.
" 470–540 " " 8 "
" 540–600 " " 9 "

Collision bulkhead not to be less than one-twentieth vessel's length from stem on upper deck.

Bureau Veritas require that no hold shall be longer than 90 feet. All bulkheads should extend to a water-tight flat well above the L.W.L., so as to have a sufficiency of reserve buoyancy when any compartment is flooded, and the collision bulkhead should always extend up to the top deck of any continuous superstructure, so that if the bows happen to be damaged in the vicinity of the deck below, the water, instead of running aft, would be confined forward of the collision bulkhead. All bulkheads should be strong enough to stand the full pressure of water on one side, and nothing on the other, without any leakage which the pumps could not easily keep under.

Lloyd's require the bulkheads to extend to the upper deck in one-, two-, and three-deck vessels, and to the spar deck in spar-deck vessels, and to the main deck in awning-deck vessels; the collision bulkhead in all cases to extend to the upper, spar, and awning decks. Lloyd's require the bulkheads to be stiffened by vertical stiffeners on one side, and horizontal stiffeners on the other, so as to leave as small unsupported bulkhead areas as possible. The vertical stiffeners are connected to tank top by bracket knees, and lower half of bulkhead plating is made heavier than the top half, to withstand the extra pressure on lower part of bulkhead, owing to the greater head of water. When the bulkhead is over a certain width, vertical plate webs are fitted, and connected to bulkheads from deck to tank top, being kneed to tank top. When the bulkhead is deep enough to require a lower deck, and one is not fitted, then a semi-box beam is required to be fitted at the level where the lower deck should be. All horizontal stiffeners are riveted either to ship's side or side stringers.

Ques. What considerations govern the arrangement of transverse water-tight bulkheads in steamers? Write down the different methods of water-tight subdivision. For what purpose are double bottoms fitted in ships?

Ans. **Methods of Subdivision.**—(1) By transverse bulkheads.

(2) By longitudinal bulkheads.

(3) By water-tight flats or decks.

(4) Double bottom.

Objects or Considerations in arranging Transverse Water-tight Bulkheads.—To subdivide the vessel into numerous water-tight compartments, so that damage may be localized, and serious loss of buoyancy and stability avoided.

The disadvantage is that the cargo stowage is broken up, and weight is added to the vessel.

Considerations in arranging Water-tight Bulkheads.—(1) *Collision bulkheads* are always carried to the upper deck, and are placed at a distance of about one-twentieth of the vessel's length aft of the stem of the lower deck.

This bulkhead has to be specially strengthened, because—

(*a*) It gives the vessel transverse strength where it is greatly required.

(*b*) It localizes damage in the case of collision.

(*c*) It takes up leakage due to panting and pounding in the fore peak.

(2) *Aft-peak bulkheads* are placed at no specified distance from the stern-post, but they are to be at a reasonable distance from same.

(*a*) In case of shaft stern tube breaking down, it localizes damage.

(*b*) It takes up leakage (from rivets, etc., due to vibration).

(*c*) It gives transverse strength.

(3) *Engine and boiler bulkheads* are arranged and carried to upper deck to separate the engines and boilers from cargo; and in twin-screw ships there is sometimes a longitudinal bulkhead fitted to upper deck to separate engines.

Arrangement of Intermediate Bulkheads.—(1) No compartment to be so large as to endanger vessel's safety should that compartment or hold become bilged.

(2) The compartments to be made of such a length as will distribute the bulkheads for strength, and bulkheads should be carried to a sufficient height, so that if the vessel was trimming by the head or stern, and she was holed in one compartment, the water would not flow over the top of bulkhead into adjoining compartments, which might happen if they were not of sufficient height.

Therefore all bulkheads are carried to the water-tight deck.

(3) All compartments at ends should be made small, to avoid excessive change of trim should it be flooded.

Purposes of Double Bottoms.—(1) Ease in working ship when in ballast.

(2) Precautions against grounding.

(3) Efficient arrangement of material to resist longitudinal bending.

CHAPTER XIV.

THE BERTH—METHOD AND PROCEDURE OF FRAMING AND PLATING—IRON AND STEEL MANUFACTURE—THE VESSEL'S STRUCTURE IN DETAIL.

Preparing the Berth.—Before a vessel can be built, the ground must be made ready to receive her. A suitable declivity is arranged, perhaps ½ inch or ⅝ inch to the foot, and the ground is then either piled or a complete concrete floor is made so that the weight of the ship can be borne without any giving of the ground. Concrete beds are more usual in Admiralty yards, or in private establishments where a great deal of Admiralty work such as battleships and heavy cruisers are constructed. In ordinary merchant yards piling is considered all that is necessary. On the top of the piles are laid heavy thwartship sleepers, the tops of these sleepers being flush with the ground. Across these are again laid the keel blocks, baulks of timber about 5 feet apart, and built up high enough to give room underneath the vessel for the workmen to work, say 4 feet to 5 feet high. As the vessel is subsequently launched at a greater declivity than when building, this height is taken right aft, and gradually increased forward to suit the proposed launching declivity. The top of the keel blocks requires sighting and adjusting so that it will be a perfectly straight line. All round the vessel, at breadths which will be governed by the size of the ship, are erected the stage poles. These are high spars of fir spilt up the centre, and pieces of wood about 4 inches wide inserted between, the whole being held together by through bolts. Resting on these are ordinary 3-inch planks, on which are again laid the staging necessary for standing platforms during construction.

The midship section shows the scantlings according to the rules or requirements of the beams, frames, reverses, floors, plating, decks, bulkheads, etc., and also a general table of riveting and the frame spacing.

Keels are of two kinds—the flat plate keel and the bar keel. The bar may be formed of one piece of solid metal, with the centre girder or floors resting on it; it may be split and the centre girder carried down between, the whole being securely riveted together. This form is known as the side bar keel arrangement.

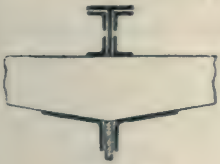


FIG. 125.

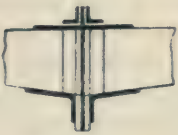


FIG. 126.

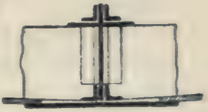


FIG. 127.

Framing comprises all the items affected by Lloyd's framing numeral—the frame bar, reverse, beam, floors, pillars, bulkheads, etc.

Framing may be transverse or longitudinal. The transverse system is almost universal in the mercantile marine, the frame bar being continuous from keel to deck, and the keelsons and other longitudinals fitted intercostally, that is, between each rib or frame. In vessels fitted with double bottoms this continuity of frame is broken at the margin plate, and a stronger vessel is really formed, because of the part introduction of the longitudinal system. The ship really only consists of the shell plating. The introduction of frames, beams, floors, keelsons, etc., is only to stiffen the shell and keep it to its work. If it were possible to build a vessel of shell plating only, and send her to sea, the plates would need to be enormously thick to withstand the blows of the sea and retain their form. Instead of this, the plating is made thin, and then stiffened to enable it to retain its form. This stiffening may be obtained either transversely or longitudinally. In the transverse system the main item of stiffening is the frame bar, as universally fitted in the mercantile marine. In the longitudinal system the main items are the fore-and-aft girders. In the transverse system, when a vessel is on the crest of a wave or in the hollow, there is a tendency for the plating to buckle, and the items which would help to resist this are the stringers; but as these stringers are all cut at the frames, much of their usefulness is lost. Now, suppose the ship has a double bottom, the great use of the margin plate is obvious in resisting buckling of the shell, as it is a continuous plate, and not cut at the frames. This is the object of the longitudinal system. All the keelsons are continuous, so that their full strength in resisting hogging and sagging stresses is utilized. These strains are the greatest a ship has to undergo.

In framing a vessel on the longitudinal system, after the keel is laid short pieces of floor are secured to it, and the first fore-and-aft girder on each side is fitted. Then the next series of short pieces of floor are fitted, then the next longitudinal, and so on, until the framing is completed. This system is the strongest, but it has the great disadvantage of being costly to build. An alternative system, termed the lattice system, now finds much favour in Admiralty work. In this every alternate keelson is intercostal, and the others continuous. With the almost universal adoption of double bottoms, the margin plate has made the transverse system really partly a longitudinal system. A great advantage of the transverse system is the great rapidity with which it may be constructed. Frames are always set off square to the centre line, and with the small flange next the shell and the long flange pointing to the centre. The rivet holes are generally punched in the frame before it is bent. The exceptions are the holes to take laps of shell plating, holes at turn of bilge, and holes in **transverse** flange for the beam knees.

To get the Position of Holes for Punching.—The batten is bent round the frame on the scrieve board and the laps are marked on it. The intermediate spaces are subdivided according to rules and transferred to the frame. Holes are punched from the **outside**, so that the **inside** of the frame will have the wider hole.

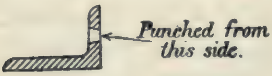


FIG. 128.

This is because rivets are swelled at the heads in hammering up.

The holes in the reverses are not punched until the bar is bent, except the holes in the fore-and-aft flange to take hold sparring. After the frames are punched they are **bent and bevelled.** These operations are performed on the **bending slabs**. Huge slabs of metal about 6 inches thick are placed close together and in front of the furnaces, and having their surface pierced about every foot with holes, say 2 inches in diameter. The faces of these slabs form a perfectly level surface, and their extent is governed by the lengths of frames which may be used. As the frames are bent and bevelled while red hot, they cannot be laid on the boards, but, instead, a piece of soft iron is bent on the boards to the required curvature of the frame. This set iron is laid on the slabs and a chalk line drawn. As iron and steel contract in cooling, the frame must not be bent hot to this line, as then it will be entirely wrong when it is cold. The experience of the frame-bender enables him to determine the exact amount of contraction to allow for (it may be inches), and the finished curve is remarkably near to the required line. Any unfairness which is noticed when the cold frame is brought to the scrieve board and tried can be made right by hammering with a heavy hammer.

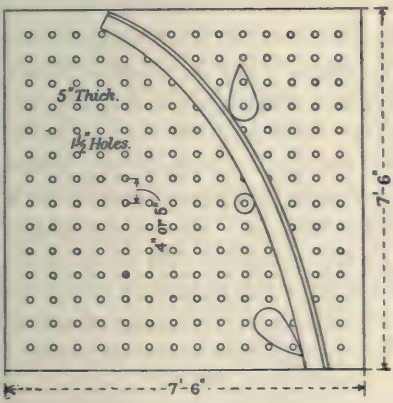


Fig. 129.

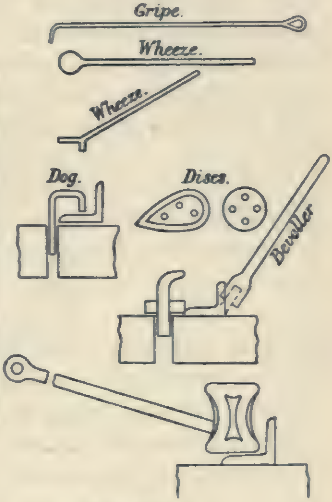


Fig. 130.

The fore-and-aft flanges of frames always look towards midships, and the transverse flange is always at right angles to the

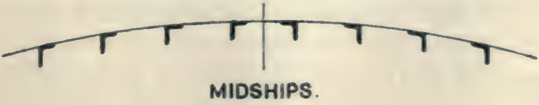


Fig. 131.

centre. An exception is in the case of a cant frame. The frame angle at the ends of a ship will be more open than those amidships, where the vessel's sides are almost straight with the centre line. When the frame angle has to be at all opened out or closed, it is said to have a bevel, either open or shut bevel. Shut bevels should be avoided, as they are very difficult to rivet. An angle may be bevelled by means of a beveller or a bevelling machine when the angle passes between two revolving wheels set to give the bevel required. Zed bars require blocks under them to raise one flange off the slabs, and the upper flange is then treated as an ordinary angle. Zed bars are bent after bevelling, and also angles where the bevel is excessive. In single-bottom ships the floors also require bending, as the wastage by cutting out the shape would be too great. The bent set iron is pinned down on the slabs, and with this as a backing the floor plate can be set to its required shape by winch purchase. Frames are, in some yards, bent by means of a small portable hydraulic ram, which pushes the frame round to its required curvature.

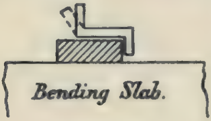


FIG. 132.

Frames are set perpendicular to the keel in most merchant ships. In some cases, say with a drop keel and in Admiralty work, frames are perpendicular to the load water-line.

As the keel in building has a certain declivity, and the frames are to be perpendicular to the keel, they will have to be in building as much per foot off the true perpendicular as the keel is off the horizontal. If the keel has a declivity of $\frac{1}{2}$ inch to the foot, and the frame is, say, 40 feet high, the top of the frame will be 40 half-inches, or 20 inches aft of the bottom of frame. The frame and beam are generally erected together, being temporarily attached. In erecting, say, the 40-feet frame, a line is dropped from the centre of the beam, and if the frame has the correct slope this line will strike the keel at 20 inches aft of the frame at keel. The beam at each side should be the same height above keel, and this can be determined by dropping plumb lines from each side. The beam should also be at right angles to the keel. To try this, a point on the keel some distance away is taken, and lines from each end to this point should be the same length. This is called **horning**, and it can also be determined by seeing that the line joining the two end plumbs is at right angles to the keel. After frames are faired, they are shored, and rib-bands of timber fastened along them fore and aft to keep their right and proper spacing, so that they will have a fair surface for plating. After frames are faired, a sheering batten is run along the top of frames to give fair deck lines, any irregularity being corrected, so that the beams may be riveted up permanently.

Beams are also faired by rib-bands in same way as frames. In double-bottomed ships the keel is usually flat, and the centre girder is erected before the frames. The floor plates, frame, and reverse in tank are usually riveted together before erecting. After being set in place, the margin plate is erected and the framing proper proceeded with as described. After frames and beams are faired, the deck stringer is laid, which, besides stiffening the shell locally, forms an attachment for the beams to the shell; the beam knee, even at best, forming a very poor means of attaching the beams to the side structure. The shell and the deck plating can now be fitted. Templates are made of each plate, giving position of rivet holes, and from these templates the plates are sheered and punched.

The inner strakes are erected first and screwed in place by bolts, and some ships have almost their entire structure plated before a single rivet is hammered in. As the plate, however carefully screwed, has a tendency to loosen, it is preferable that riveting should commence as soon after as possible. While the plating is being proceeded with the bulkheads are erected, the wood decks laid, and the superstructures, such as poops, bridges, forecastles, and deck houses, can be got in place.

IRON AND STEEL MANUFACTURE.

It is the almost universal practice now to use steel for merchant and Admiralty vessels. In countries where small sailing ships are built, and where timber is present in abundant quantities, that material is still employed. Iron also is sometimes used in parts of a ship, such as angles and plates under boilers, where corrosion is very rapid; iron forgings and castings for stem and stern-post, timber heads, fairleads, bollards, etc., on deck; the stanchions and pillars in vessel's holds, and the rivets for holding together the structure.

Difference between Iron and Steel.—The steel used for ships' plates is really only a form of iron. The difference between iron and steel can be best explained by a short account of the methods of production.

Iron.—The ore after quarrying is melted and run into moulds, giving pig iron. This pig iron contains, along with the pure metal, impurities, such as carbon, phosphorus, manganese, etc. The pig iron is placed in a furnace and subjected to an intense heat, which passes over the top of the metal.

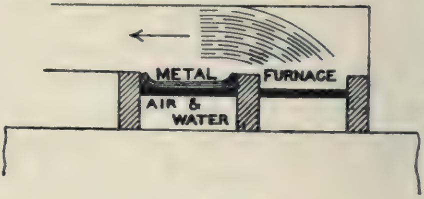


Fig. 133.

To prevent the iron deteriorating, streams of air and water pass under it, while to induce greater surface heat the already fierce heat of the flames are made still hotter by introducing a surplus of oxygen. All the time the metal is being continually stirred by the puddler, and the impurities in the iron are soon consumed. When it has passed through several phases, the puddler gathers it together in balls about a foot in diameter and removes it from the furnace. It is then taken to a hammer and dealt some ten or twenty blows, which remove some of the still remaining impurities. After this process it is passed through grooved rollers, the grooves being graduated, and in the end it comes out as a tough elastic bar of malleable iron. To make this into plates it is passed between smooth rollers, which are gradually screwed down to the required thickness. From this continual rolling the iron acquires a fibre, as in wood, and it is found to be stronger along the grain of fibre than across it.

Steel.—In the making of steel the pig iron is melted in the furnace hearth, and then scraps of wrought iron, etc., are thrown in. The melting process is carried on till the metal is entirely free from carbon, the result being obtained by the carbon in the pig iron mixing with the excess of oxygen introduced and forming carbon dioxide. When the carbon has been completely eliminated, *the exact proportion of carbon required is thrown in,* together with manganese, the carbon hardening the soft iron and the manganese counteracting the evil effects of impurities, such as sulphur and phosphorus, which cannot be got rid of. The mass is now poured directly into moulds, which are allowed to cool slowly, the moulds being afterwards converted into the required shape by milling and rolling. Pouring the molten metal directly into moulds is the cause of the non-fibrous texture of steel plates and angles. The amount of carbon introduced determines the hardness of the steel.

Iron contains a certain amount of carbon, etc., which is never got rid of, and is in fact necessary. Steel contains an exact percentage of carbon. Iron is taken from the furnace in spongy balls and rolled. Steel is poured direct from the furnace into the moulds. Steel must first get all the carbon removed, as the exact amount of carbon present cannot be ascertained. After it is removed the exact amount necessary is added.

THE VESSEL'S STRUCTURE IN DETAIL.

Keels.—Keels may be either flat or bar. Where draught is limited, flat keels are fitted, and in cargo steamers are almost universal. The bar keel is perhaps the stronger arrangement, and is also of great use in reducing rolling. With this form of keel, intercostal or continuous centre keelsons need not be fitted except along the tops of floors. With the flat plate keel either intercostal or continuous centre girders are invariably associated. The keel, either bar or flat plate, is the first part of a ship's structure to be erected.

Stem and Stern-post.—These may be either forgings or castings, and are the heaviest forgings or castings in the ship. The weight of the post especially has led some owners to devise other forms, but their success has been only moderate, and the stern-post to-day is very similar to that as originally designed. In sailing ships, of course, the stern-post is not so heavy, but in screw steamers it becomes a serious item of weight, a vessel of, say, 400 feet having a stern-post weighing perhaps 20 tons. The shell connecting rivets have generally only their hammering ends heated, as it is found that if the whole rivet is heated the contraction of the metal in cooling tends to crack the head of the rivet.

Frames.—The commonest form of frames is the combination of two ordinary angles known as the frame and reverse. This may be modified, as in the case of the zed frame, channel frame, and bulb-angle frame, the latter being extensively used in coal and grain vessels. Channels and zed frames are not usually fitted at the ends because of the difficulty in bevelling them.

Floors.—Across the bottom of the ship are fitted the floor plates, with the frame angle along the bottom edge and the reverse bar on their upper edge. These are the chief sources of strength to the bottom of the vessel. Where there is not a centre keelson, the floors either run from side to side in one plate, or they are butted or lapped either at the centre or alternately on each side of the centre line and treble riveted. The floors at bulkheads extend sufficiently high to give a clear riveting landing for the lowest plate of the bulkhead.

Keelsons are fitted either along the top of the floor or intercostally between floors, except the centre keelson, which is often a continuous plate with the floors stopping against it.

Beams are useful in tying together the upper ends of opposite frames, and also form a framework on which to lay the deck. They complete the transverse girder formed with the frame, reverse, and floor. The round up of the beam towards the centre allows any water on deck to run off into the gutter way at the side, and also strengthens the section. Angle bulb and plain channels, zed and tee bars and bulbs are employed for beams, and the combination of channel beams and channel frames makes a very quickly constructed and efficient form of girder. In the way of large openings, such as engine and boiler spaces, where beams cannot be built to rule spacing, heavy beams are fitted, consisting generally of channels one frame space apart, and tied together by a web of plating on top. Or the heavy beam may consist of two channels or bulb angles back to back on the same frame. As in some stresses the force acts directly on the beam knee, it is important that the connection of the beam to the frame should be thoroughly sound. The plate knee, although sometimes not used on passenger decks for appearance' sake, is the strongest job, as the welded knee, when bulb beams are employed, loses much of its efficiency by the defective methods employed of preserving the continuity of the bulb.

Stringers and Decks.—With the stringer, tie plates are always laid on beams where there is no steel deck. Stringers and ties, and wood deck or steel deck, contribute to both the longitudinal and transverse strength of the ship. They hold the beams to their work and in their place. They form the top flange of the box girder completed by the side and bottom plating. They stiffen the shell in the locality, and tie, by means of the stringer angle, the beams to the shell. They form a platform and water-tight cover for the ship's cargo and make the vessel seaworthy. The stringer plate being put on first is always an inside strake. The other strakes of plating may be alternately all in and all out (A), or one edge overlapping the edge of the adjacent plate (B).

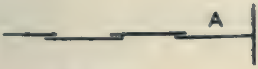


Fig. 134.

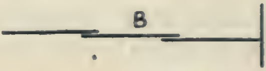


Fig. 135.

A variation of system A is to joggle the outside strakes and obviate the fitting of liners on the beams. Where no wood deck is fitted on the steel deck, system B should be adopted, as it permits of the water shedding off the deck into the gutter waterway, and leaving no pools at the raised edge, as would happen with system A. Where wood deck is fitted, system A is preferable, permitting as it does of planks of even thickness being fitted. Before fitting planking, the steel deck should be well coated with paint or bitumen, to preserve the plating should any leakage occur in the planking. The planks being square, the camber of deck leaves them a little open on the upper surface. This should be caulked with oakum and payed or filled in with water-resisting glue, pitch, or composition. A special mouthing, two-thirds the depth of plank, should be put on the plank edges for better caulking purposes. When deck plates are all in and all out alternately, the planks on the inside strakes will be thicker than those on the outside strakes. Sometimes the planks are laid to the lesser thickness, and packing pieces of wood laid on the inside strakes to make the surface of planking a fair surface. This custom has nothing to commend it save cheapness.

Pillars.—Pillars are primarily supports for the deck or beams. They are also ties between the beams and the floors, and serve to keep both their proper distance apart, resisting any forces tending to bring them closer together or pull them wider apart. Both ends then should be equally well connected. If a beam is efficiently supported, say, at the centre by a pillar, the length of beam is really reduced to half for bearing purposes, and the force or stress of the load tending to break it is correspondingly reduced. The diameter of the pillar depends greatly on its length, as the longer it is, the greater diameter it must be. Pillars are usually of round iron and solid, but may be fitted as channels, round plates as masting, hollow round iron, half-round iron, or of H bars.

When pillars are built as masting or H bars, they are usually associated with a special system of deck support, requiring, perhaps, only one or two pillars in the entire hold. Half-round pillars are sometimes fitted in grain-carrying vessels, to take the grain boards, being arranged in couples with about 3 inches space in between, and are also fitted in the upper structures of some passenger-carrying vessels, the flat of the pillar taking the cabin linings, etc.

Hollow pillars, although more costly, have less weight for the same strength of solid round iron.

Pillars may be broken in various ways. Cast iron may sheer; wrought-iron pillars may bulge or spread; long wrought-iron pillars may buckle. When the ratio of length to diameter is very great, the pillar may first bend, and then the force acting on it will act as if it were a beam and break it, the inner side being crushed and the outer side torn apart. The resistance of a round iron pillar to bending varies as the square of the proportion of least diameter to length.

Double Bottoms.—The first use of a double bottom is to carry water ballast. This water ballast can be used in certain conditions of lading, where the margin of safety is small, and it makes the ship more stable in that condition and therefore a safer boat. In a case of the vessel tearing a hole in the bottom, the inner skin of the double bottom will prevent the water entering and causing the ship to founder. By subdividing the double bottom about the water-tight bulkheads into separate compartments, the vessel can be brought into almost any required trim by filling some of the tanks. When a vessel is sailing light the double bottom can be filled, and give deeper immersion and greater stability. It is comparatively easy to examine the shell plating, and to paint it if required. When the double bottom alone is used, as for example when vessel is sailing light, the effect of such a heavy weight so low down makes the ship very unmanageable, through rolling heavily and thus steering badly. If the inner skin could be continued, as in Admiralty vessels, right up the side to, say, the freeboard deck, it would make a much easier ship. This system takes up cargo space. A vessel requires floors. Making the floors a little deeper, and plating the top to form a double bottom, does not take up so much space as if the same amount of water had to be carried at the sides. Except in the Admiralty service and a few isolated ships of the mercantile marine, the water ballast is carried low down between the floors. A method which has not obtained the success it seems entitled to, is to make the really waste space between the hatches on weather decks into tanks, by plating level with tops and hatches, and carrying the winches on this platform. Longitudinal deck girders of great structural value could be made by the hatch sides being continuous fore and aft, and in the ballast condition the filling of these tanks would have a very appreciable easing effect on the ship. In the double bottom ordinary arrangement, the centre keelson and the margin plates on each side are continuous. The deep floors are continuous between these, and the intermediate keelsons are fitted intercostally. In small vessels, only alternate floors are complete, the other consisting only of brackets to centre keelson and margin plate, and heavy frame and reverse angle. For vessels in which ordinary floors have been fitted, water ballast may be carried by fitting longitudinal girders on top of the floors and covering with plating. Such an arrangement is known as a McIntyre tank, and is sometimes fitted in new vessels where the double bottom only extends for a short distance of the vessel's length. Water ballast is carried because of the ease and rapidity with which the tanks may be filled or emptied, but unless tanks are completely filled they may become dangerous to the ship's safety.

Shell Plating.—The shell plating forms the main item of longitudinal strength, and is also by far the heaviest item of the ship's structure. Plating may be arranged in alternate in-and-out strakes, with packing liners fitted between the frames and the outside strakes to give a bearing surface for riveting. The packing may be dispensed with by joggling the plating and making it bear hard on the frames, or joggling the frame to suit the strakes. When some stress comes on the ship tending to stretch the plating, the rivet holes punched in the plates are a source of weakness. Especially is this so at a water-tight bulkhead, where holes are punched, say, every 3 inches. Bulkhead liners are here introduced in way of the outside strakes, and these help to bring up the sectional area of the section. When joggling takes place, these liners cannot be fitted, unless in frame joggling, when the joggling can be omitted in the frames adjacent to the water-tight bulkhead. Some vessels, such as steam yachts, have the shell plating flushed, that is, each strake of plating butting hard against each other. The edges are strapped on the inside, with straps intercostal between, and bearing tight against the frames. The seams are caulked on the outside. This is generally only fitted above water. Under water the ordinary clencher system is carried out. The shell is extra thick at three places, the keel or garboard strakes, the bilge strakes, and the sheer strake, because these are the parts likely to meet the greatest stresses. In extra long vessels, where the bending moment will be excessive, the sheer strake will have to take very great stresses, and in some vessels it will be required to be double for perhaps half or three-fourths the length amidships. The bilge strakes, when the sheer strake is under tension, will be in compression, and they also in long ships require additional strengthening, usually obtained by adding one-twentieth, two-twentieths, three-twentieths, etc., to their thickness. A strake of plating is weakest at the butts, and it is necessary, to obtain a strong section in each frame space, to have as few butts as possible in that frame space.

With butts properly distributed it is possible, even in large vessels, to have only, say, two or three butts in a frame space. If a vessel had outside plates, say 6 feet broad and two butts in the frame space, she would have a total breadth of 12 feet of cut plating, or equal to three butts if the strakes were only 4 feet wide. It is for this reason that a limit of breadth of strakes is insisted on by the classification societies. All parts which are weakened by close riveting, or cutting of openings, require compensation. This applies to all structural parts, and the compensation is obtained by thickening the plate or adding a local doubling.

Bulkheads.—Bulkheads may be transverse or longitudinal, water-tight or non-water-tight (partition), of wood or of steel. Vessels, and especially steamers, require certain water-tight bulkheads for safety. These divide the ship into a number of water-tight compartments, and it is possible for one or more compartments to be bilged and full of water and the ship still remain afloat. Some steamers can remain afloat with three compartments full of water. The longitudinal weakness at a water-tight bulkhead can be partly compensated for, and their transverse strength is very great. Bulkheads divide the vessel into separate holds, and allow different cargoes to be carried. Longitudinal water-tight bulkheads in a long hold are very dangerous, as, if one side is bilged and full of water, there is a tendency for the vessel to capsize. Admiralty vessels are divided both longitudinally and transversely into a great many water-tight compartments, but this is not profitable in a merchant ship, where large bulky cargoes are carried. Where water-tight bulkheads are stepped, the deck or flat must be made water-tight. As the water pressure, if a compartment is flooded, will be greatest on the lower part of the bulkhead, this part must be made stronger, and the stiffening at the bottom securely attached, either by brackets at the tank top or in ordinary floors by scarfing well down. Longitudinal bulkheads of wood are fitted in such vessels as carry grain, etc. While this does not strengthen the ship, it makes her safer by not permitting the grain, when the vessel heels, to sally towards the listed side. Transverse wooden bulkheads are fitted sometimes at bunkers, or when a temporary subdivision of a hold is required.

Poop, Bridge, and Forecastle.—The poop, by lifting the stern further out of the water, prevents a following sea from falling on the ship. It provides a safe structure for holding the steering gear. Officers' accommodation is sometimes fitted up in the poop; but in vessels other than passenger vessels the poop is usually fitted to carry cargo of a light or bulky kind. The poop, by raising the counter or overhang, allows the load water-line and the general run off of the lines to be much sweeter. The bridge is an important part of a ship's structure. The most severe stresses are longitudinal, and occur amidships. The bridge increases the depth of the ship where it is most required, and makes her much stronger. It protects, in a steamer, the vital parts of the machinery, and allows the casings to be carried, perhaps, 8 feet or 10 feet higher than in a flush decker, thus increasing the vessel's safety. The front bulkhead of the bridge requires to be stoutly built, and serves to effectually stop seas which break over the forward well. Light cargo in cargo steamers is carried in the bridge, and any reserve coal required. The forecastle forms a house for berthing the crew. It prevents seas from breaking over the bows, and gives a "drier" ship. It strengthens the fore part of the vessel, which has to meet heavy blows of the sea. By extending the forecastle, cargo can also be carried here. The poop, bridge, and forecastle spaces can, by leaving a small opening not detrimental to the vessel's safety, be made to evade the tonnage laws, and consequently cargo is here carried without the owners paying duty on it. For vessels trading East through the Suez Canal, poop, bridge, and forecastle spaces are added on to the tonnage. The following concessions are, however, made:—A forecastle is allowed to be one-eighth of the vessel's length; a poop is allowed to be one-tenth of the vessel's length; a bridge is allowed to be the length of the engine and boiler rooms. Any lengths of erections beyond these limits are added on to the Suez tonnage.

Quarter Decks.—In some steamers the upper deck is stepped about 3 feet to 4 feet higher, and then continued in a fair line to the stern. This abrupt breakage of the line of strength requires to be compensated for, and the compensation is obtained by having a long overlap of the two decks. The raised after part, called the raised quarter deck, and the upper deck overlap perhaps eleven frame spaces. This method of construction is chiefly for tonnage purposes, although in vessels having their machinery aft it is sometimes necessary for housing the engines and boilers under deck. Although the line of deck is broken, the sheer strake runs aft in a fair line, and thus in way of the quarter deck the upper strake is not the sheer strake. At the break, the sheer strake should be doubled, and adjacent plating specially strengthened in order to maintain the continuity of longitudinal strength.

Panting Arrangements.—The word "panting" conveys at once the meaning intended. At midships a vessel may be compared to a hollow square girder. At the ends the breadth is reduced to very little. The transverse stiffening has been in great part lost. The vessel here has a tendency to develop flexibility, the side plating tending to pant, or bulge in and out alternately. To prevent this, breasthooks, panting stringers, etc., are fitted. Breasthooks are the end plates which tie the two side stringers together. There is, say, 8 feet between deck of unsupported side plating and framing. At midship no stiffening is necessary, but at the extreme ends a side stringer halfway between decks is introduced, and at the ends strongly tied together by breasthooks. This stringer is called a panting stringer.

Bilge keels are fitted to reduce rolling, while at the same time offering very little resistance to forward motion. The line of bilge keel should be carefully considered, so that it may take approximately the line of least resistance to flowing water. A general mean trim line is usually adopted. In the merchant service, bilge keels are not usually more than 1 foot deep, and consist of a bulb bee or some similar form riveted to the bilge strake. In Admiralty vessels the semicircular form of the section, and the required immunity from rolling for gun-fire, requires a much larger bilge keel, and they are fitted from 3 feet to 4 feet deep of built plates V-shaped.

Rivets.—Rivets may be of steel or iron, but it is customary in many yards to use iron rivets for almost all work. The steel rivet requires more care in heating and hammering, and the bad results of steel riveting, although arising chiefly from careless workmanship, have caused this rivet to be looked on with disfavour by some builders. The riveting is done chiefly by hand, although it is possible to rivet by hydraulic power some parts of the structure, such as frame to reverse, all floors, tank intercostals, centre girder, keel plate, and garboard sheer strake, and strake below sheer, etc. The limit to the use of the hydraulic riveter is the inaccessibility of the plate or angle to be riveted, the jaws of the riveter being only 5 feet or 6 feet long.

Pneumatic and electric riveters have been tried, but their success in ship riveting has been only moderate. A practical mechanical riveter has yet to be invented, and is growing more absolutely necessary every day. It may be that the method employed now of connecting plating and angles together by rivets will be superseded, and a scheme of electric welding take its place. Rivets are of several forms—panhead, snaphead, countersunk-head; and these heads are associated with either boiler, flush, snap, or bat point. The hydraulic riveter finishes the heads and points snapform. The snapform, from its superior appearance, is largely used in parts of the ship where the riveting is always exposed. Where rivet-holes do not exactly coincide they may be made to receive the rivet by means of a drift punch. Where the error in punching has been very small, this method of forcing a passage for the rivet may be permissible, but rivet holes that overlap much should be rimered or drilled fair and a larger rivet used. Tap rivets are chiefly used to connect parts of the plating to forgings, castings, or in places where it is difficult to get at the back of the rivet for holding up. It consists of a screw with a projecting head, afterwards chipped off, for screwing it home.

Hatches.—The almost universal method of getting cargo into a ship is by openings in the decks. These openings are of necessity very large, and are thus a source of deck weakness. The decks in way of hatchways, and especially at the corners, must be efficiently compensated by doubling plates or thickened deck plating. The hatch coamings can be made stout enough to recover some of the lost longitudinal strength, and the openings should be bridged transversely by strong portable web beams. In the wells of vessels green seas or vast solid masses of water sometimes sweep over the bulwarks. The coamings here must be made high enough, so that only a small amount of this water will be pressing on the hatch covers. The hatch covers should be at least 3 inches thick, to prevent them breaking under the load of water, which might in a short time cause the vessel to founder. There is no doubt that a vast number of vessels, and especially coasters, are lost through hatches giving way and the seas pouring into the hold. All weather hatches should have tarpaulins over the covers, and securely battened.

Derricks.—While steel masts have almost entirely displaced wooden masts, yet steel derricks are looked at with disfavour by most shipowners. Even in a sailing ship, where the mast has such tremendous strains to undergo, the steel mast is almost universal. The cause of the objection to steel derricks is hard to discover. They are lighter, last longer, and are theoretically stronger. A wooden derrick to lift 30 tons lay on a steamer's deck for two voyages to the East and was never used. On completing the second voyage, the derrick was examined, and the action of sun and weather on the wood had so destroyed it that it was condemned as useless for lifting even 10 tons. With light-lifting derricks, the cheapness of the timber and ease in making are very strong points in their favour, but in heavy derricks there seems no reason why steel should not be as universal as in masting.

Masts.—Masts are usually raked or sloped aft, for appearance, although in cargo steamers the rake is very slight, and in some even perpendicular, as the derricks work much smoother when the heel of the derrick and the head of the span are in the same vertical line. The diameter and scantlings of masts are determined by the classification society under whose rules the vessel is built. The steel for masts must be of special quality, as the plates require great working and bending in mast making. The diameter of a mast is greatest at the wedging (usually at the upper deck). The diameter at the head is five-eighths and at the heel three-fourths of the diameter at the wedging. The landings are double riveted and the butts treble riveted. The top masts are usually made of wood.

QUESTIONS ON CHAPTER XIV.

Ques. Describe the tests to which steel plates and zed bars are subjected to, to ascertain if they are fit for use.

Ans. **Steel Plates.**—To be able to stand a tensile strain of not less than 28 and not exceeding 32 tons per square inch, with an elongation equal to at least 16 per cent. on a length of 8 inches.

Lloyd's, 26–30 tons, and 20 per cent. elongation on a length of 8 inches.

Admiralty, high tensile steel to stand 37–43 tons per square inch.

Samples taken from every batch of plates and planed into required shape 8 inches × 1 inch × 1 inch are placed in testing machine which registers number of tons' strain. If mild steel bears a strain of more than 32 tons, it is too brittle, and would not stand other tests. In breaking, the plate generally breaks across at an angle of about 40°.

Bending Tests.—Strips of plate heated to a low cherry-red, and cooled in water of 82° F., to be bent round a curve, of which the diameter is not more than three times the thickness of the strip.

Plates heated and cooled in water of 82° F. to bring frost out if in wintertime.

Zed bars may have a maximum tensile strength of 33 tons per square inch. Bars to stand both hot and cold tests. A length of about 2 inches taken as a test piece.

(1) Flanges of the bar must be able to be bent double to within their own thickness of each other.

(2) Bent out flat again without breaking.

(3) Bar to be bent double longitudinally and strip cut lengthwise from bar 1½ inch wide, to be pulled the same test as plates.

Ques. Give pitch and size of rivets for different thicknesses of steel plates to Lloyd's rules; and give pitch of single, double, and treble riveted butt straps, single and double chain, and double zigzag riveting, in diameters.

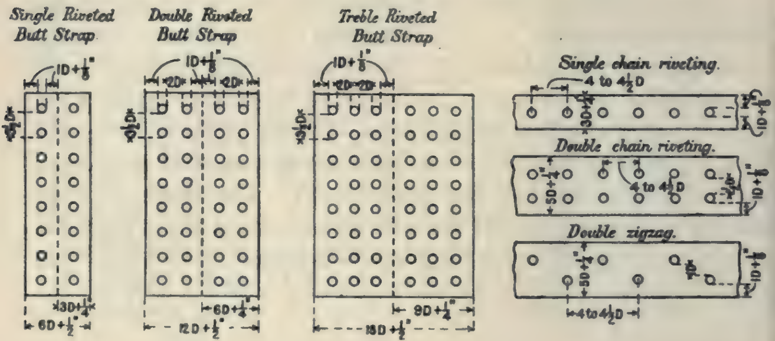


FIG. 136.

Ans. **Steel Plates.**

$\frac{5}{20}$ to $\frac{6}{20}$ = $\frac{5}{8}$ inch rivets
$\frac{7}{20}$ " $\frac{9}{20}$ = $\frac{3}{4}$ " "
$\frac{10}{20}$ " $\frac{13}{20}$ = $\frac{7}{8}$ " "
$\frac{14}{20}$ " $\frac{16}{20}$ = 1 " "

Ques. Sketch and describe three methods of connecting beams to frames.

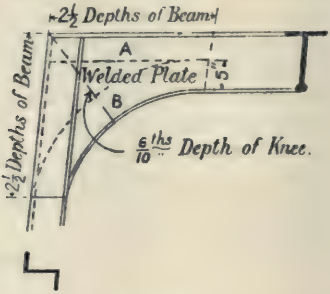


FIG. 137.

Ans. (1) **Bent or Welded Knees.**—In the way of the knee the beam is sawn up the middle, and the top part, A, runs up to the heel of frame (or ½ inch shorter), and lower part, B, is bent down. The beam is ordered 8 inches or 9 inches longer to allow for the bend of the throat. Each arm to be two and a half times the depth of beam, and the throat one and a half times depth of beam, or six-tenths depth of knee. This kind of beam is seldom adopted unless in specified work, and is very expensive.

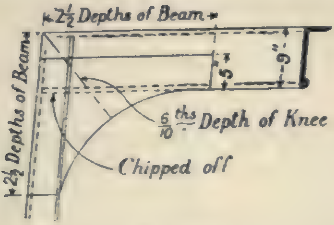


Fig. 138.

(2) **Bracket Knee Plates** are commonly used.

Where the bracket plate is connected to the beam, if a bulb, the bulb on one side is cut off to leave a plane surface for riveting.

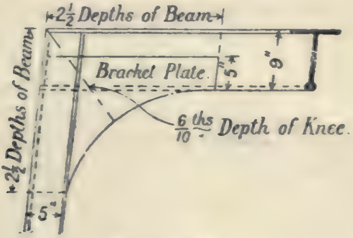


Fig. 139.

(3) **Slabbed Knee.**—This method is not so commonly used, and, as in the bracket knee, the half-bulb is chipped off where in way of slab.

This knee is not so efficient as the split knee.

Ques. Sketch water-ballast tank on Cellular and McIntyre systems.

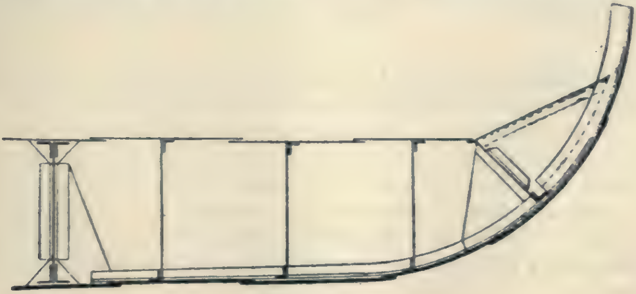


Fig. 140.

Ans. (1) Cellular tanks with floor on alternate frames. When this kind of cellular tank is fitted with floors on alternate frames and brackets on intermediate frames, Lloyd's require three girders to be fitted. Girders to be spaced from 3 feet 6 inches to 4 feet apart.

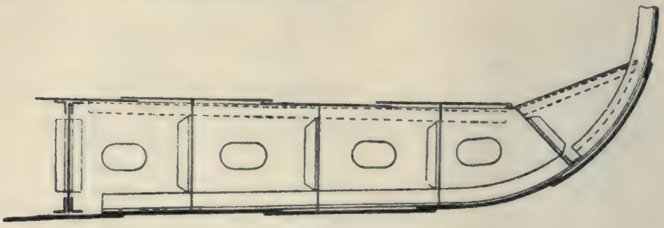


FIG. 141.

(2) In vessels having double bottom with continuous floors on every frame, floors must have one girder if breadth is 34 feet or under; from 34 feet to 44 feet, two girders are required; 3 inches drain holes to be cut as low as possible.

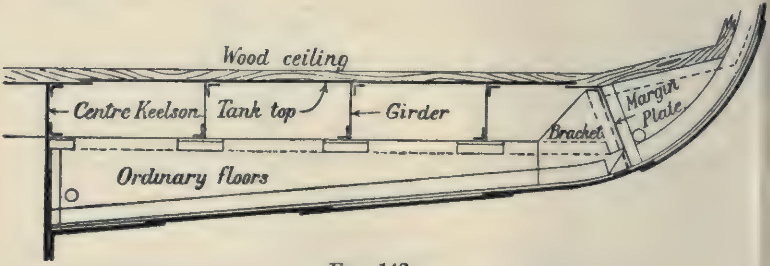


FIG. 142.

(3) McIntyre tank is a tank built on ordinary floor arrangement. Used in repair jobs, where vessel has no ballast tank, and also where tanks only run for short distance.

Ques. State the sections of moulded steel in general use for shipbuilding purposes, and say for what part of the structure each is used.

Ans. The thicknesses of plates that are rolled are from $\frac{1}{8}$ inch to 3 inches. But in exceptional cases, as in armour-clad ships, it is generally the case that the plates are 6 inches or more in thickness. Plates are used for tank-top shell, decks, side-houses, casings, margin plates, ties, floors, bilge clogs, etc.

Angles are used for stiffeners, frames, beams, collars, corner pieces, etc.

Bulb angles are used for beams, stiffeners, keelson bars, and sometimes frames.

Tees and bulb tees, or butterfly beams, are used for beams, stiffeners, etc

Zed bars are used for framing, beams, stiffeners.

Channel beams are used for beams, frames, stiffeners, pillars.

Bulb plates are used for keelsons, beams, stiffeners.

Square and oblong bars are used for all kinds of smithwork.

Round solid bars are used for rail bars, stanchions, pillars, and other items in smithwork.

Flat bars are used in smithwork, and for packing.

Round tubes are used for pillars, and by boilermakers and plumbers.

Half-round, *convex*, *feather-edge*, or *hollow half-round*, are used for mouldings, ornamental work, etc.

O.G. sections are used chiefly for hatch rests. Hatch rests are also other sections, such as Tyzask's.

Patent rail sections are used for bulwark tops.

Jackstay bars are fitted on masts to take jackstay travellers for lifting or lowering sails.

Ques. What are the advantages in using zed steel for the transverse frames as compared with frames formed of two angle bars? Are there any disadvantages?

Ans. **Advantages.**—It has less sectional area than the two bars of equal strength; therefore is lighter.

When it is bent there is only one bar as against two bars which have to be bent and taken to the scrieve board.

There are no holes punched in the transverse flange (excepting beam knees or cargo cleats); thus saving labour and cost in riveting.

Takes the place of a reverse bar on the top of the outside tank brackets.

Disadvantages.—They are difficult to bend and bevel and handle (or adjust), requiring special blocks.

That a ship with ordinary floors could not very well be built on the zed-frame system, unless the zed bar was carred to the keel and a reverse bar fitted from bilge along the top of the floors, which is expensive, and is extra weight; therefore it is preferable to build an ordinary floored ship with the two bars, viz. main bar and the reverse bar.

Not used when the bevel is excessive, namely, at the fore and after ends.

Very difficult to repair.

In almost all ships reverses do not require to be carried so high as frames. With zed frames this concession would be lost.

Ques. Make a drawing to scale of a tank side margin plate, showing its connection to the tank side knees, floor plate, tank top and shell. Show the riveting, stating pitches in diameters.

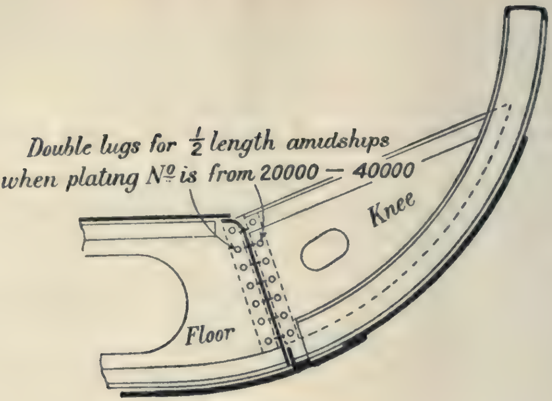

Double lugs for $\frac{1}{2}$ length amidships
when plating No. is from 20000 — 40000
Knee
Floor

Fig. 143.

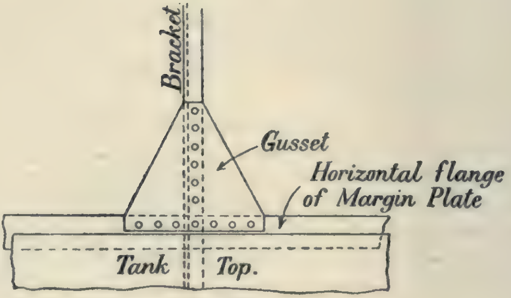


Fig. 144.

Ques. Give sketches and descriptions of some of the forms of keels you are acquainted with, and show and describe how the various parts are attached to the ship and to each other.

Ans. The first kind is the bar keel. This consists of a continuous slab in lengths of about 40 feet connected to each other by tack rivets, and connected to the garboard strake by large rivets which should be ¼ inch larger than those required in garboard strake, but in no case need they be larger than 1¼ inch. They are spaced zigzag five diameters apart, and countersunk

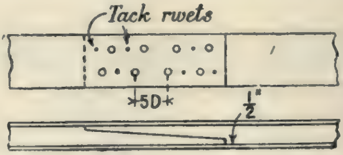


Fig. 145.

for the thickness of garboard strakes. The tack rivets are about ¾ inch diameter, and there are generally about six in each scarph. The scarphs are in length nine times the width of the keel.

The garboard strake is bent and turned down the side of the keel. It is stopped about 1¼ inch short of the bottom of the keel to allow for caulking.

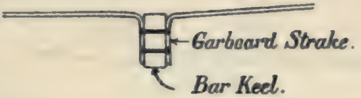


FIG. 146.

The second keel is the side bar keel, and is formed of three separate thicknesses. The first is a centre keelson, which extends right to the tank top, and is connected to it by double angles, and also connected to each floor by double angles. On each side of the keelson, as shown, is fitted a slab, the same depth as a bar keel for the same sized ship—the thickness of the three together to be equal to the bar keel. The slabs should be fitted in as long lengths as possible, say 50 feet, and the centre keelson and garboard strakes, say 24 feet, or 26 feet. This enables one to get a good shift of butts. The garboard strake is turned down in the same way as in the first case, and the five thicknesses riveted with the usual rivets spaced five diameters apart. Care would, of course, have to be taken to have the holes drilled fairly in the slabs, and punched to suit the plates, as there are five thicknesses to be riveted together.

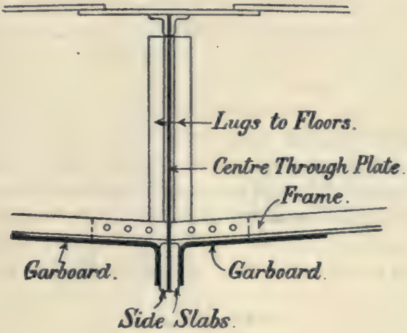


FIG. 147.

The third kind is the flat plate keel. In this case the centre keelson stands in the centre of the keel plate, square to it, and is connected to it by double angles. The plates can be either strapped or overlapped. When strapped, straps are fitted top and bottom, as shown. The rivets through the angle bars to keel are the usual diameters and spacing (reeled), and the rivets through centre keelson and bars are spaced seven diameters. In vessels which have a plating number of 26,000 and above the keel has to be doubled for half-length amidships. In lieu of this doubling, the keel and garboard strakes may be thickened.

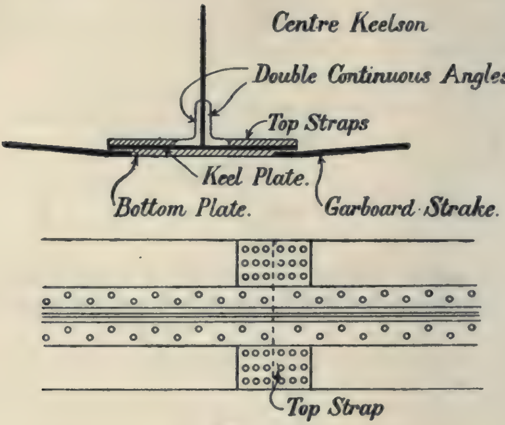


FIG. 148.

Ques. Distinguish between natural and artificial ventilation as applied to ships. Describe in general terms, with sketches, the system of ventilation adopted in any vessel with which you may be acquainted.

Ans. Natural ventilation is the ventilation due to natural causes, such as the admittance and escape of air by means of hatches, doors, openings, and cowls, placed so as to catch the wind, and allow the hot air to escape from any compartment.

Artificial ventilation is ventilation secured by artificial means, such as steam and electric fans, which either suck the fresh air down openings and drive the foul air out, or else expel the hot air and so allow fresh air to take its place.

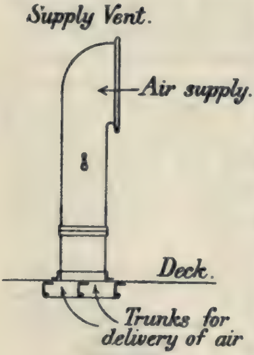


FIG. 149.

In a good class cargo boat the following system of ventilation may be adopted. Into each hold at the after end, close to the bulkhead on each side of the ship, cowl ventilators are placed, facing the direction in which the ship travels. These catch the wind caused by the vessel's motion, and deliver it, by means of trunks which run along under the deck and down the side of the ship, to the deck of each compartment. The air entering low down in each compartment, as it does, drives the foul air forward and to the top of each compartment, where it escapes by openings in each deck stringer, and is led by means of trunks to an upcast ventilator at the fore end, as shown in the sketch, thus allowing the foul air to escape.

The engine-room is ventilated by means of two large cowl ventilators, one at each side, which extend down as far as practicable into the engine room, and deliver a stream of cold air, the hot air rising and escaping through a large skylight on top of the casing. The stokehold is ventilated also by means of two cowl ventilators, which introduce fresh air into it, drive the foul air into the furnaces, and so up the uptake into the funnel, the length of the funnel assisting this. Often two upcast ventilators, as shown in the sketch, are fitted above the boiler tops in the casing, to take out the hot air rising from boilers. The stokehold bulkhead may have a space of, say 12 inches width for its whole depth and breadth, enclosed by a wood bulkhead in the hold. By supply and exhaust pipes air is led in, which keeps the bulkhead from getting too hot and so damaging cargo in the hold. The tanks can have the foul air extracted by means of pipes led up to the deck, having goosenecks fitted above the deck. The tunnel may be ventilated by a cowl ventilator fitted at deck, with tube extending down to after recess. The berths are either ventilated by mushroom ventilators, together with the side lights and shutter openings in the alley bulkhead door, top and bottom; or cowl vents may be used in connection with the other means named, the saloon often having a skylight fitted over it. The water-closets have either cowl or gooseneck ventilators fitted to extract the foul air; the stores being fitted in a similar manner. Forward, where there are crew spaces and stores

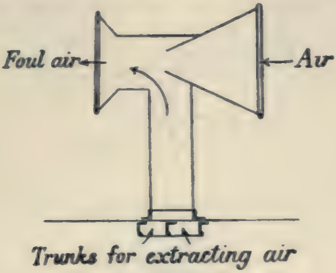


FIG. 150.

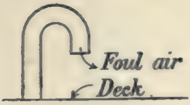


FIG. 151.

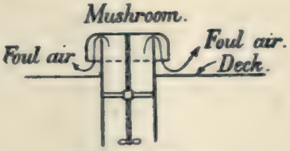


FIG. 152.

on several decks to ventilate, a cowl ventilator is fitted which has a smaller tube fitted at each deck as it descends, and so allows air to rise between each tube at the different decks.

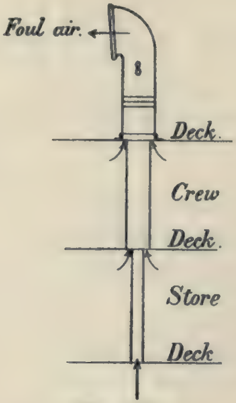


Fig. 153.

Ques. Sketch and describe the usual steering arrangements of a merchant steamer, showing both the hand and steam gears, giving the materials and the approximate principal dimensions.

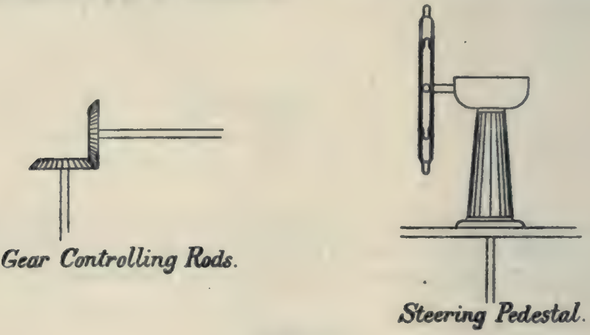

Gear Controlling Rods.
Steering Pedestal.

Fig. 154.

Ans. The ship is usually steered by means of a small hand-wheel fixed on a pedestal on top of the chart house. This wheel, as will be seen by the sketch, controls a steam gear by means of rods and bevel wheels. The steam gear rotates a barrel on the upper deck, round which the steering chain is keyed on to the rudder stock. Just above the passenger deck is a forged iron quadrant tiller, usually having a plate riveted to the back of the forging, and angle bar on the outside edge to form channels for the steering chains.

A chain is fastened at each corner running in separate channels, and being led to the opposite sides of the ship. The chain goes round a large quarter block, placed so that when the rudder is hard over, the line of the chain is tangential to the curve of the quadrant. This chain is led round another smaller block, or more down on to the upper deck. Further along the deck is fitted and connected to the chain a spring buffer, being a strong steel spring fitted in a forged iron case. The other end of the buffer is connected to long rods where there is not much curve of deck line. As this approaches the after end of the bridge, the steering chain is again introduced, and connected to the end of the rod. This chain passes round another large quarter block, and so on to the barrel on the extended shaft. It passes round the barrel, and along the other side of the ship in a similar manner, and so connected to the quadrant tiller.

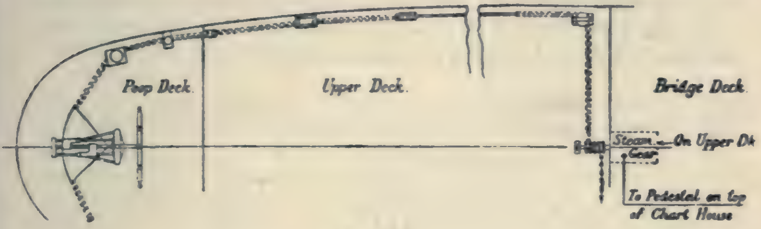


FIG. 155.

There is thus a continuous connection from the quadrant tiller and back again. Sometimes smaller buffers are introduced between the steering-gear barrel and the quarter block. By turning the wheel on the top of the chart house, the quadrant, as will easily be seen, can be turned to either side, thus turning the rudder. The quadrant often has rollers fixed to it, and rolls in the proper path on the deck, thus taking the weight off the rudder stock.

To prevent the rudder from going over too far—limit usually about 40°—stoppers are fixed either on the arms of the rudder stays or else on the stern-post gudgeons, and stops are also fitted on the deck to prevent the tiller going too far over. The spring buffers take up any shocks given to the rudder by the sea, and thus save straining the steam gear. Keyed on to the rudder head is fixed a crosshead, which turns the rudder by means of a hand-screw gear in the event of the steam gear breaking down. Some ships have a steam and hand combined gear, so that in the event of the steam gear controlling rods going wrong, the steam gear can still be controlled. Lastly, if both steam and hand gears were rendered useless, the quadrant tiller could be turned by means of relieving tackle.

MATERIALS AND APPROXIMATE SIZES.—**Quarter Blocks.**—Cast iron, about 24 inches diameter.

Steam Gear.—As per detail sketch.

Steam Gear.—Controlling rods. Wrought steel, 1¼ inch, diameter with 5-inch brass bevel wheels.

Steering Chain Links.—⅞ inch thick.

Steering Rods.—2½ inches thick, wrought iron.

Spring Buffer.—Wrought-steel spring in forged-iron case, about 2 feet 6 inches long by 3½ inches diameter.

Quadrant Tiller.—Forged arms, with plate riveted on radius about 5 feet depth of arms, and rudder about 8½ inches.

Rudder Head.—8½ inches diameter.

Hand Gear.—Mostly cast steel with thread about 3½ inches diameter. Crosshead, wrought iron, about 2 feet 9 inches across, and 6-inch teak steering wheel.

Ques. Make a sketch of a boat's davit, giving the cleats and blocks attached to it. Show the method of securing a boat in-board, and state how the position of the davits is fixed in relation to the boat.

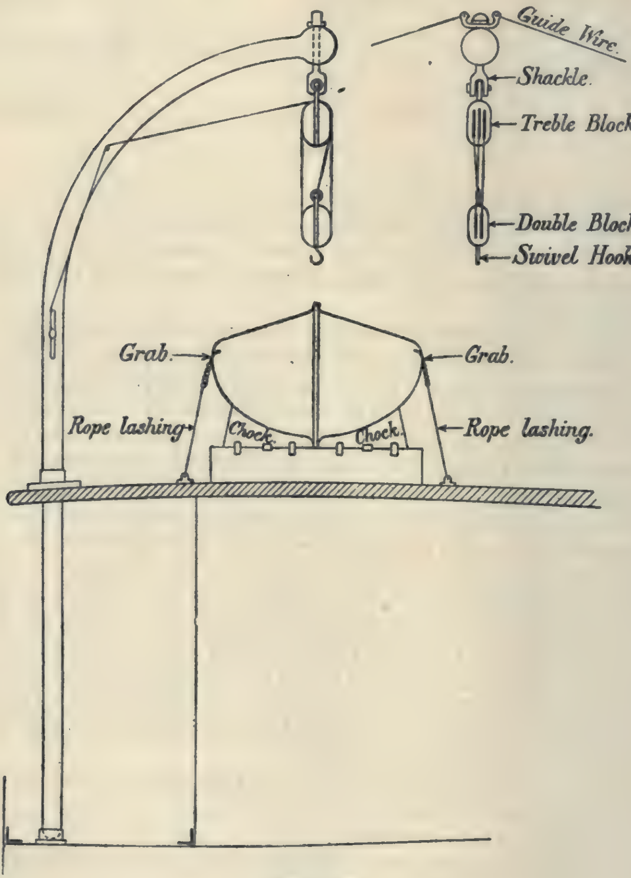


FIG. 156.

Ans. The boat is secured as shown on sketch. The boat chocks rest on the promenade deck or top of deck house, and the bottom part is fixed with the top part, made so as to hinge down on deck when the boat is lifted, and the wooden keys shown in sketch are driven out. Chain grabs, about two on each side of boat, are arranged to grip the gunwale of the boat, and are lashed tight up by means of rope lashing through an eye at the end of the grabs, and secured to a ring bolt on the deck. The davits are arranged at equal distances from each end of the boat, and the distance between is such that when the davits are swung round, the end of the boat can be pushed out-board between the davits, and then the boat can be swung out clear. The davits must have enough spread to take the boat out clear of the broadest part of the ship's side, and must be high enough to allow of the fall being worked over the blocks to lift the boat clear of the chocks.

Ques. Show how you would proceed to take account of the several parts of a steel lower mast which has considerable rake and taper, in order that the materials may be ordered from the manufacturer.

Ans. Having given from Lloyd's rules, or any other classification society's rules, the diameters at heel, deck, and head, proceed as follows:—Set off,

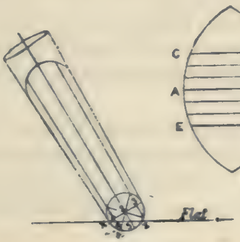


FIG. 157.

full size if possible, the diameter at deck, as AB, and at each point A and B, with AB as radius, describe intersecting circles as shown in sketch.

Above and below AB respectively, and parallel to it, draw in lines CD and EF, such that they represent the diameter at head and heel respectively. Divide the distance between the deck line, head and heel lines, into a number of equal spaces, and draw lines parallel to AB, meeting the circumference of the circles which have AB as diameter. Along centre line set off on ½-inch

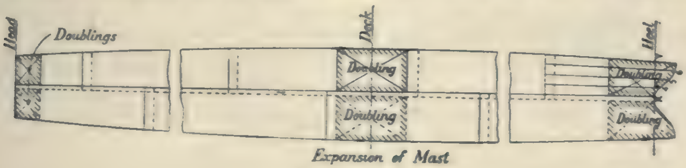


FIG. 158.

scale the diameters from deck to head and heel, and divide each into the same number of equally divided parts as was done in the first case. Draw perpendiculars, and on each set off the respective full-size half-diameter, lifted from the diagram. Run in a fair line through these spots by means of a batten. Arrange the positions of the butts, and lift the half-diameters at each.

On the same centre line as the first. set off, at the positions of the butts on each side, the calculated half-circumference, and run a fair curve through the spots obtained, allowing two or more laps according to the diameters of the mast. One-half of the mast, owing to the lap, will have a bigger diameter than the other, and in calculating the half-circumferences this must be taken into account.

The plates, with the exception of the plates at heel of mast, are now ready for ordering. To obtain these, divide the half-circumference, at the first butt in each strake, into a number of equally divided parts, and at the point X at heel of mast draw XY square to the centre line. Divide the half-circumference of the mast into the same number of parts as at the butt, and join the points obtained, producing them to meet XZ. Now expand the half-circumference at each butt and at XY, with the points 1, 2, 3, etc., marked on them. Join these, and lifting the distances from their respective points on XY to where the lines cut XZ, set them off on their relative lines in the expansion. Run a line through the points obtained, and you have the heel developed.

The plates can now be ordered allowing for laps, and allow 1 inch on lengths, and ½ inch to 1 inch on breadths of all plates. Doublings can be lifted from the expansion and ordered in a similar manner to the plates.

Ques. Describe, with sketches, how the shaft tunnel in a large single-screw ship is constructed, and state the sizes of plates and angles and rivets used.

Point out how the tunnel is formed into a water-tight compartment, and what means are taken to clear out water which has collected in it.

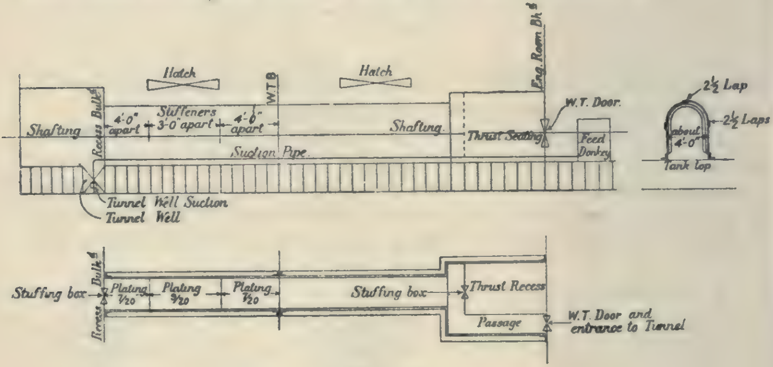


FIG. 159.

Ans. (1) The tunnel of a vessel is built to encase the shafting, and sometimes to carry water ballast.

(2) It is built of angles and plates, for which Lloyd's specify scantlings.

(3) The plating runs longitudinally, and the bar stiffeners transversely.

(4) The tunnel plating is made the same thickness as the lower half of the bulkhead plating, and in way of hatches it is increased $\frac{2}{20}$ inch, or is cleaded with wood.

(5) Stiffeners are same size as reverse frames, spaced 4 feet apart, and 3 feet in way of hatches.

(6) Usually the plating is made up of three strakes, viz. two side plates, and the top plate is rounded to the top of the tunnel.

(7) The tunnel is connected to the tank top, recess bulkhead and engine-room bulkheads by 3½ inches × 3½ inches bars, the height of tunnel being based on lines of shafting.

Riveting ¾ inch.

In stiffeners, seven diameters apart.

In boundary bars, four to four and a half diameters apart.

In edges of plating, four to four and a half diameters apart.

When fitted to carry Water Ballast.—(1) The stiffeners would be placed closer.

(2) Riveting in the seams will remain the same.

(3) The edges of the tunnel plating should be always well caulked.

(4) A water-tight door would be fitted on the engine-room bulkhead, capable of being opened and closed from above the W.L.

(5) The recess and engine-room ends of tunnel should always be made perfectly water-tight with the bulkheads.

To dispose of Water which has collected in the Tunnel.—(1) A tunnel well is fitted aft of the recess bulkhead.

(2) The vessel would usually be trimming by the stern, therefore the water would drain into the tunnel well.

(3) A suction is fitted in the well, and the water is pumped therefrom, the suction pipe being led along the tunnel floor to the ballast donkey-engine.

Ques. Describe the lamp method of sighting keel blocks.

Ans. The keel sights are at first nailed about 1 inch below the bar, spaced from 60 feet to 80 feet apart, and are set level by means of a spirit-level. Then after dark a light is placed behind the end sight opposite the slit, and a man looks through the slit at the other end, and they are raised or lowered until the lights can be seen. The reason for keeping the sights slightly below the keel is to admit of their being raised or lowered as required.

Ques. Sketch and fully describe the various methods of laying and arranging keel blocks, stating what determines the declivity, height amidships, and at fore end.

Ans. The following items have to be considered in the laying out of keel blocks:—

(1) The ground must naturally be suitable for the purpose of building ships, and have a suitable declivity.

(2) When it is not naturally suitable, special preparations have to be made, as for example—

(*a*) Slag balls are put into the ground, and the surface spread over to render it hard, and make the declivity.

(*b*) Clay or concrete blocks are put into the ground, and the surface spread over.

(*c*) Piles are driven into the ground.

(*d*) In dockyards and several private shipyards, the ground in way of the blocks is paved with granite, so that it will bear the heavy weights which are constantly placed upon it.

Arrangement of Keel Blocks.—In the case of piling, the piles are arranged in groups of three, fore and aft, in way of the keel, and in pairs, fore and aft, in way of bilge blocks.

Cross baulks, or fore-and-afters, are used, so that by means of the cross baulks the strain on the keel blocks may be eased a little on to the bilge blocks, to prevent the piles from becoming infirm, and also to stiffen the ground.

Keel Blocks.—(1) These are generally built up to height most suitable for the men to work under and still be as low as possible.

(2) There must also be a sufficiency of light and air underneath the bottom of the ship, to obviate the necessity for artificial light as much as possible.

In the case of a fast and light vessel, whose bottom has a large rise of floor, the height of the blocks is about 3 feet 6 inches; then there is plenty of room and light for the men to work, without any artificial light; it also allows the riveters a good swing for their hammers.

When in the case of a large cargo boat, there is a wide bottom and small rise of floor, the height of the keel blocks varies from 3 feet 6 inches to 5 feet, and in many cases artificial light is required under the ship's bottom to enable platers, caulkers, and riveters to work.

There are two kinds of keel blocks, double and single.

In most shipyards a double block is placed alternately along the bottom of the ship.

The single method is an old style of arranging blocks, and is fast dying out, chiefly because they have a tendency to trip.

To prevent this tripping, spur shores are diagonally fitted from top to bottom of every block, and also planks which embrace three blocks.

Ques. Explain how the bevel of a frame is obtained, and how the bevelling board is prepared and applied by the frame turner.

Ans. The bevels are lifted for every frame, and are taken from the scrieve board. As the frames look towards midships, the amount of bevel in a frame space will be the distance between one frame and the next frame towards midships, measured square to frame. These distances are measured every 4 feet, then by means of an instrument called a bevelled frame, or bevel lifter (see sketch), the bevels are marked on a board the breadth of frame.

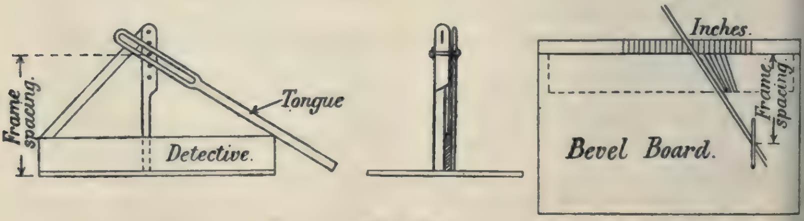


Fig. 160.

A bevelling board is put in the instrument, and the pointer moved to the first distance measured from the board, and a line drawn across bevelling board to this; the bevelling board is then moved along a short distance, and the next bevel marked, and so on. Or the bevel could be lifted from the boards by the bevelling instrument. If a bevelling machine is in use, the frame turner marks the different bevels of the frames on a dial with chalk, and as the frame is being passed through the machine, the rollers are moved to suit the different bevels, there being a dial on the machine showing the distance the frame has passed through. After the frame is turned the bevels are tested and altered where necessary. If frames are bevelled by hand, a bevelling wheeze is applied, and the bevels tried in the different positions until a correct bevel is obtained.

Ques. How are the frames, reverse frames, and floor plates of a mercantile iron or steel vessel of the ordinary type adjusted and proved upon the scrieve board before riveting them together?

Ans. **To adjust Frames.**—After the frames have been bent, they are next adjusted on scrieve board by placing each frame to its required line to see if it is true. If a frame should happen to be a little untrue, hammers are held on the one side while it is struck by another hammer on the opposite side, thus forcing it into its proper shape. If the frame is a great deal out, a tool called a squeezer is used, which, when screwed up, forces the frame to desired shape.

Reverse frame is adjusted by placing it on frame where they are both of the same curve.

Floor plates after being turned are also adjusted by placing them on their respective stations. Frame and reverse frame are then placed on floor and marked; then floor is punched and sheered.

Ques. A portion of the framing of an iron or steel ship being in place on the blocks, explain the method of proceeding with the plating of the bottom.

Ans. (1) **To Fair Plating Lines on Ship.**—Position of plate edges are indicated by a mark on, say, every fifth frame, and a lathe is pinned to these marks and sighted.

Keel plate is placed on blocks before framing.

To Plate Bottom.—Order of erecting plates on vessel—

(*a*) Inside strakes.
(*b*) In-and-out strakes.
(*c*) Outside strakes.

Templating.—Construct wood template from ship, obtaining position of plate from plan and lifting the holes in way of frames. Holes are not drilled, but simply marked on template by means of whiting and pin.

(2) **To mark Plate.**—Template is now placed on plate a little below top and marked. Rivet holes are transferred on to plate by means of reversers, using white paint to mark plate. Punch plate from faying surface, and sheer plate at machine to required size.

(3) **Rolling and Screwing.**—Set irons are lifted on every frame in way of plate. Plate is then rolled to meet sets; if any fore and aft set, place plate in rollers end first; pieces of wood placed on plate at each side makes it

gradually develop to its required set. Screw up plate on ship with bolts, treating the rest of the plates for inside strakes more or less in the same manner.

If plate does not screw tight, owing to not having correct set, leave it for twenty-four hours, and then retighten the bolts, and plate will now be found to screw tight.

(4) Fair plate lines on inside strakes for outside strakes.

(5) **Erect** in-and-out strakes into position on ship.

(6) Construct template, lifting seams, frames, butts, etc., treating plates same as for inside strakes, and punch plates from inside.

(7) **To joggle Plates.**—Some yards adopt the process of joggling the outside strakes where practical. Plates are first joggled, then rolled, $\frac{1}{20}$ inch being allowed on joggle for rolling.

Ques. How are the beam knee bevels obtained and applied by the beam maker?

Ans. From the scrieve board. Lift sheer heights vertical on a lath, and set them off on centre line from deck at centre; now move mould up to each of these spots, taking care to keep mould at same centre, marking on the mould the bevels of the beam knees at each frame, the bevels being the run of the frame which intersects the mould at each of the various frames, thus obtaining both bevel and the lengths of all the beams. The fore end bevels are marked on one side of mould for both sides of ship; then turned over, and after end marked on, ready for beam maker, who lays mould on beams, and marks the length, adjusts the beams, and cuts them off at their various bevels.

Ques. Explain in general terms the order and method of lining in, on the frames at the ship, the lines of a large steel ship, so that the work of framing, plating, etc., may be proceeded with.

Ans. On the scrieve board, when the frames are bent, the lines of the plate edges, decks and side stringers are marked on the frame. On the floor-plate top the positions of the keelsons (if any) are nicked on the bars.

Keelsons.—(1) Correct the centre line of ship on top of the floors by striking a line through nicks which were put on at the boards.

(2) The same to be done for side keelsons.

(3) When the above lines are faired, the holes for the lugs and longitudinal keelson bars may be marked.

Side Keelsons.—(1) Lath off through scrieve board marks on frames, the faired line of the stringers.

(2) When the line is faired, mark the new position on the toe of the bar with a cold chisel.

(3) After this the plater can proceed with the templating of the stringer.

Deck Plating.—(1) Strike a line full length of ship, from centre of stem to centre of post. Mark correct width of hatches.

(2) From deck plan mark off width of stringer on, say, every fourth frame from side of ship. Fair this up.

(3) Then start from centre and mark off breadths of plating. Usually

the plate at centre goes half to each side. In this case the half-breadth of it is put from centre, and the other breadths from this.

(4) Mark off landing holes after these are faired. Make plate next to stringer the closer or finishing plate.

Shell.—(1) The plater will have a copy of plate book, with the widths of strakes and position of butts marked therein.

(2) Set off the position of the butts of garboard strake and size of each butt.

(3) From plate book get the width of the other strakes up to bilge. Put these on same way from bottom of ship, allowing for the laps.

(4) Sight these to fair up. When finished to please, mark in with cold chisel.

(5) Mark on width of lap.

(6) Take a template specially made, and mark off landing hole in lap.

(7) Work down from sheer strake to bilge in same way, making bilge strake the closer.

Ques. Show how to take an account of and get in place a bottom plate which has—

(1) Slight curvature and no twist.

(2) Great curvature and excessive twist.

Ans. For example, take an inside plate just under the bilge when there is **a slight curvature.**

(1) The plate starts, say, with an inside strake under the bilge.

(2) A template is made to the size of the plate to be fitted.

(3) A piece of iron about $\frac{3}{4}$ inch × $\frac{1}{8}$ inch, called a set iron, is bent to the curvature of the frame.

(4) When the strake has been lined off and template made, it is put up and attached in place by means of clips or hutch hooks. The holes in frames are marked on template by a marking pin and whiting, care being taken that the ends of the template are exactly in the middle of frame space where the butt comes.

(5) When the template is marked, it is placed on plate, and positions of holes transferred to plate, either by centre punch or reverser.

(6) Being an inside strake, the butt connection of lap holes are taken from a template made in the mould loft, and transferred to plate; the edge lap holes are also spaced on plate according to Lloyd's spacing for edge laps, as there are only the frame holes which can be taken off the ship (for an inside strake) on the template.

(7) Mark off length and breadth of plate, care to be taken that frame holes are marked on faying surface.

(8) Punch the holes from faying surface.

(9) Countersink the frame holes on outside surface, not countersinking edge and lap holes.

(10) Sheer and plane the edges, if necessary.

(11) The plate is then taken to the rolls and bent to the required curvature.

(12) The plate, being now practically finished, is taken to the ship, hoisted in place, and screwed up tightly with service bolts.

Note.—When the centre punch is used, the plate is nicked through the centre of the holes marked on the template, and when template is taken off plate, the positions of these holes are marked with whiting, taking each nick as centre.

Great Curvature and Excessive Twist.—(1) Fair the sight edges, and mark off on the frames the true outline of the plate.

(2) A skeleton mould is then made at the ship, either welded or riveted together, the mould being made of strips of iron, $\frac{3}{4}$ inch or 1 inch × $\frac{1}{8}$ inch.

(3) When the skeleton mould is bent or hammered to the real shape of, say, the oxter plate, it is taken to the bending slab.

(4) A cradle to the form of the oxter plate is built up at the furnace mouth.

(5) The plate is neither punched nor cut, but put into furnace just as ordered, and there heated to a bright red.

Note.—The oxter plate is always ordered about two-twentieths thicker than nett thickness, to compensate for loss of strength due to hammering.

(6) The plate is always larger than nett size when heated.

(7) The plate when heated is taken from furnace, placed on the cradle, and hammered down to the edge of the skeleton mould.

(8) If necessary, the plate is reheated.

(9) The plate is allowed to cool very slowly, which is termed "annealing."

(10) It is then taken to the ship and held in position by shores, etc.

(11) The holes are then marked through the frames, etc., on to the plate and butt; it is also marked for shape.

(12) The plate is taken down, and holes punched where possible, and drilled where impossible to punch, and cut to shape.

(13) It is next taken to the ship and tightly screwed in place, care being taken that plate fays against the frames.

(14) The plate can now be riveted up and chipped fair on edges for caulking.

Order of Riveting.—(1) First, the frames starting from the centre and working sideways towards the ends, to prevent buckling.

(2) Next, along edge of plates.

(3) Rivet up the butts.

Ques. Describe the operations carried out on the bending slabs for bending ship's frames.

Ans. Before a frame is bent, the rivet holes, with certain exceptions, are punched, these exceptions being the ones at the turn of the bilge, and in way of plate landings. In order to obtain the proper position of the shell rivets, a batten is bent round the frame on the scrieve board, and the position of the plate landings, keelsons, and decks are marked on it, the position of the rivets in the landings being determined. The intermediate spaces are subdivided so as to obtain as nearly as possible the spacing of seven diameters. The holes which pass through the landings are not marked on the frames, as they must be accurately set off after the frames are in the ship, so that they may be at the correct distance from the edge of the plate. When the frame rivets are marked upon the batten, the latter is laid upon the angle or channel to be used for that particular frame, and the rivet holes transferred to the proper flange of the bar. The holes for the reverse bar are set off in a similar manner, care being taken to have the correct spacing in way of the bracket, and to the necessary height. When these holes are all marked, the holes for the beam knees are set off from a template, which is placed on the frame with its upper edge at the position of the deck as marked on the frame, from the first-mentioned batten. The height of the deck is marked on the frame with three chisel marks, thus

Keelsons are also cut in with a chisel, their distinguishing shape being

The centres of the plate landings are marked with a notch on the edge of the heel of the frame. When all this has been done, the frame is punched, and it is usual to leave a little piece, say 4 inches, at each end, when setting off the rivets, to allow for come and go during the bending process. In bending the frames, the first operation is the preparation of the "set iron." This is a bar of soft iron, from about 2½ inches × ¾ inch to 1¼ inch × ⅜ inch, according to the size of the frame. The set iron is bent accurately to the curve of the frame on the scrieve board, each frame being traced out in chalk, as required, and the position of the bevelling spots marked on it. It is then taken to the bending slabs, and the curvature transferred thereto with a thin slip of chalk. This curve, drawn upon the bending slabs, is that of the outside of the frames, and at a parallel distance from it, equal to the width of the frame, is set off, by means of a gauge, the curve of the inside edge of the frame. It is usual to draw another line on the bending slabs a short distance from the first, so that after the frame is bent it may be checked from this without removing from the slabs. As it is found on cooling that a bent angle bar not only shrinks but loses a portion of its curvature, a point is therefore fixed several inches beyond that given by the set to allow for contraction in cooling. A point is also fixed within each extremity of the curve of the inside of the frame, and the set is adjusted to pass through these points. In this way several inches' greater curvature is given to the frame than shown by the scrieve board to allow for straightening during cooling. This curvature sometimes amounts to an extra 6 inches at each end in a 40-feet frame. The set is fixed to the slabs by dogs, and backed up by lopsided, square-headed pins, driven into the holes in the bending slab. Taper wedges are also used where necessary. All this time the bar is in the furnace, being heated to a bright redness, almost to whiteness. When ready, it is taken out of the furnace, and one end of the bar is fixed at the required place by pins on both sides of the bar, then a chain is fixed at the other end, and the men pull it round as far as possible, and the remaining curvature to make it lie against the set iron is given to it by a lever called a wheeze.

As the bending proceeds, the bar is fastened with dogs and pins to keep it up to the set iron, and from buckling. The set iron which gives the curvature for one side has only to be reversed, and fixed in the position given by lines which had been drawn similar to the first ones.

When the frames are nearly cold, they are tried on the chalk line which was made from the set. If they are correct, they are taken to the scrieve board, where they are finally and carefully adjusted. If they happen to have too little curvature, lay the frame down on the slabs, and place a pin at each side about 3 feet or 4 feet apart. Then a block and tackle is fastened to the end, and by pulling at this, together with hammering the standing flange, the required curvature is given to it. When the curvature of frame is too great, it is taken out by laying the horizontal flange on an anvil convenient to slabs, and hammering it along the inside edge.

It is usual to give a little too much curvature, as it is easier to take out curvature than to put it in when the bars are cold.

Ques. What is a declivity batten, and how is it applied? Describe the method of sighting blocks.

Ans. A declivity batten is a batten about 15 feet long × 9 inches, or 11 inches × 1½ inch, with a cleat screwed on so much per foot for spirit-level, for applying on top of keel blocks to correct declivity.

Method of sighting Keel Blocks.—The fore-and-after end blocks are first arranged to the declivity required; another is then placed amidships, and sighted in line with the other two; the remaining blocks are then spaced off, and built up in line with sights, and corrected with declivity batten. Another method is to set up the end blocks as before; with a midship one sighted in line with these, a steel wire is stretched from one end to the midship block, and made taut with a pinching screw; the intervening blocks are then built up to this line. The same process is gone through with the blocks between midship and the other end.

Ques. How are the entrances into double-bottom compartments made water-tight? Show how such compartments may be sounded, and state what provision is made for the escape of air when the compartments are being filled with water.

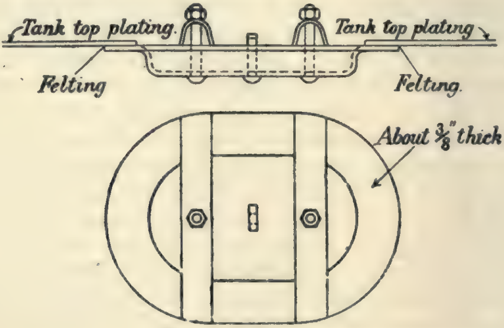


FIG. 161.

Ans. The entrances into double-bottom compartments are usually manholes, and they are made water-tight in the following manner. An iron plate is cut out the shape of the manhole, allowing a lap of about 2 inches all round. About eight ¾-inch holes are tapped in the lap, and in corresponding positions in tank top these holes are larger, about 1 inch in diameter. A piece of red-leaded felt or indiarubber is cut for tap bolts. The cover is then held in position under the tank top with the felt between, and screwed up tight by ¾-inch tap bolts with a washer between head of bolt and tank top. Sometimes a piece of cord is taken right round the lap, on each side of the tap bolts, before screwing tight. A common form of patent manhole door is shown in sketch. This pattern of door does away with the necessity for the tap bolts. When a tank is being filled, the air escapes through pipes which run from the deck to the tank top at each side of the ship at the highest part of the tank, usually the fore end. They are often taken up the side of the vessel to avoid damage, and sometimes instead of stopping just above the deck, and having brass covers fitted, they are carried a little above, and form a gooseneck, thus leaving the mouth of the pipe open. The method for sounding a tank is as follows:—An iron rod about 5 feet or 6 feet long, is chalked and fastened to a long line. It is lowered down a pipe placed at the deepest part of the tank, which runs close to bottom of tank, and, if possible, against some bulkhead, until it touches the bottom of the tank. The depth of water in the tank is obtained by measuring the wet portion of the rod from bottom.

Ques. An ordinary steel deck is to be covered with planking. State the order in which the work will be proceeded with, and show how the planking will be fastened.

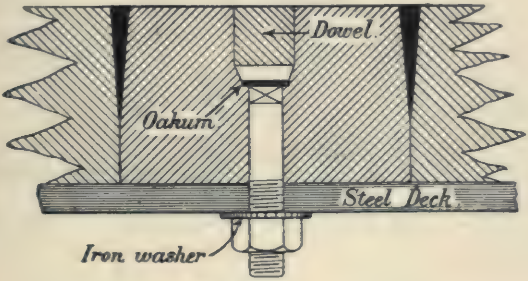


FIG. 162.

Ans. The first thing to be done is to line off the breadth of the margin plank, usually a wide teak plank, from the heel of the waterway bar, and drill holes about 4 feet apart between the beams in the deck plating, to allow the fastening to come through. The butts are arranged, and the planks cut to their correct lengths. Then one plank is laid in place, and a man goes underneath the deck, and with an augur makes a hole in the plank to correspond with the hole in deck. This hole is widened to about 1¼ inch diameter for about 1½ inch down from top of wood plank. A hemp grummet, red-leaded, is then placed round the neck of the fastening below the flat head, and the bolt is then placed in its position with the thread underneath the deck. Another grummet is placed round this portion against under side of deck, and the nut placed on and screwed up tight. Then a cylindrical piece of wood, with the bottom end coated with white lead, is jammed into the space between the top of the wood deck and the head of the fastening. As it is driven in, the white lead comes up the sides and makes a water-tight job. There are two fastenings at each side of the butts. After the margin plank has been fitted all fore and aft, the lines for the edges of the remainder of the planking are marked off, and holes drilled as before in the deck plating; every plank being fastened about every 4 feet. The first strake of planking is usually one which is clear of all obstructions, such as hatches, etc., and runs uninterrupted all fore and aft. The butts for this strake, and remaining strakes, are arranged, as a rule, so that no two butts come transversely opposite to each other, unless there are at least three strakes between. The planks are fastened in the same manner as the margin plank, except that there are only single fastenings. The edges of the planks are tapered a little at the top, as shown in sketch, to allow of the seams being caulked with oakum and pitch, or marine glue. The butts are also caulked in a similar manner. At the ends, where the planks meet the margin planks, the latter is notched, and the plank run into it. It is then caulked. When all that has to be connected to the iron deck has been done, the remainder of the planking can be laid in the usual manner.

Ques. Describe how a large water-tight bulkhead is constructed and secured in position, and the riveting you would suggest.

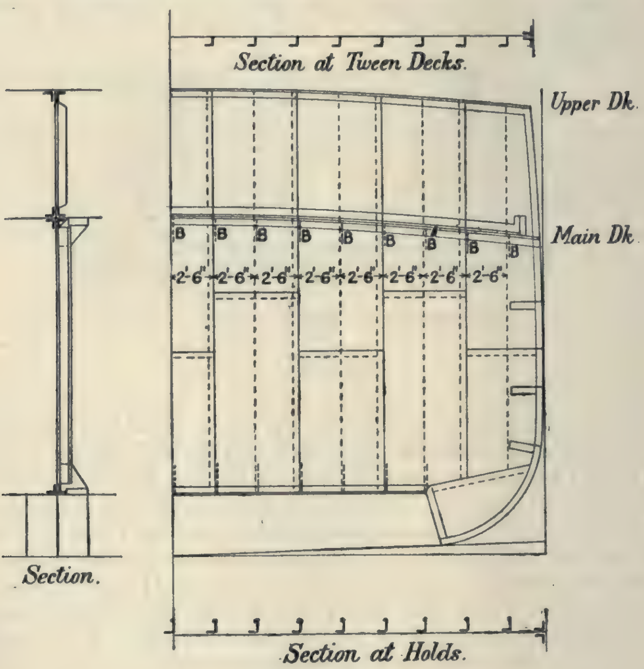


Fig. 163.

Ans. A water-tight bulkhead is usually plated with plates single riveted; the thickness of the plates being regulated by the frame number, the lower half being thicker than the upper half. It is connected at deck and tank top by double angles, and to the shell by means of double frames. It is stiffened on one side by vertical, bulb-angle stiffeners, spaced 2 feet 6 inches apart (kneed to tank top), on the other side by means of horizontal bulb angles spaced 4 feet apart, and kneed to shell. If the bulkhead be from 36 feet to 45 feet deep, there must be a vertical web connected to it, and to deck and tank top; if it is from 45 feet to 55 feet deep, there must be two vertical webs; and if from 55 feet to 60 feet deep, there must be three vertical webs. If the bulkhead is deep enough to require deck beams between main deck and tank top, and is not supported on both sides by a lower deck, then a semibox beam must be fitted across the bulkhead, and connected to the side stringer which is midway between the main deck and the tank top. Riveting at seams, and butts, and bars, connecting bulkhead to shell, tank top, and deck, would be four and a half diameters apart centre to centre, and rivets in stiffeners, seven diameters to eight diameters centre to centre. The side stringers are either run through bulkhead, and made water-tight by means of collars riveted round it, or they are stopped and connected to bulkhead by large brackets or knees.

Ques. What are the characteristic qualities of the following shipbuilding materials?—

1. Yellow pine;
2. East Indian teak;
3. Cast steel; and
4. Wrought iron.

Ans. 1. **Yellow pine** is a wood which possesses a fine, close grain, little sapwood, and is very uniform. It has a greater amount of strength, durability, and hardness than any other pine. It is used in the decks of cargo boats, owing to its lightness and solidity. As its name implies, it has a yellowish cast.

2. **East Indian teak** is a hard wood, brownish in colour, strong, and durable. It is soon seasoned and easily worked. It is good for all jobs where exposed to the changes in the atmosphere. It is much used for weather decks of passenger boats, and for margin planks in pine decks.

3. **Cast steel.**—This is obtained from pig iron by adding carbon, silicon, etc. It possesses more carbon than the mild steel used for plates. It is not at all malleable, but is not so brittle as cast iron, and possesses considerable hardness. Is much used now instead of forged iron for rudders and stern frames. All these castings are annealed to produce uniformity of temperament.

4. **Wrought iron** is obtained by puddling or working pig iron when heated till it is a soft, spongy mass, in a furnace. It is very malleable, and fairly ductile, but cannot be tempered. It is used for stanchion iron, davit iron, etc. It has three qualities, B, BB, BBB. These are obtained by reheating and rerolling, which improve the quality. This material has a good tensile strength, and can be welded.

Ques. Make a sketch of a left- and right-handed screw steering gear, giving the sizes and materials of the various parts.

Ans. MATERIALS.—**Crosshead C.**—Cast steel shrunk or keyed on to the rudder head.

Slide Rods R.—Steel (good wrought).

Sleeves S.—Cast steel brushed with gunmetal.

End Standards.—Of cast steel.

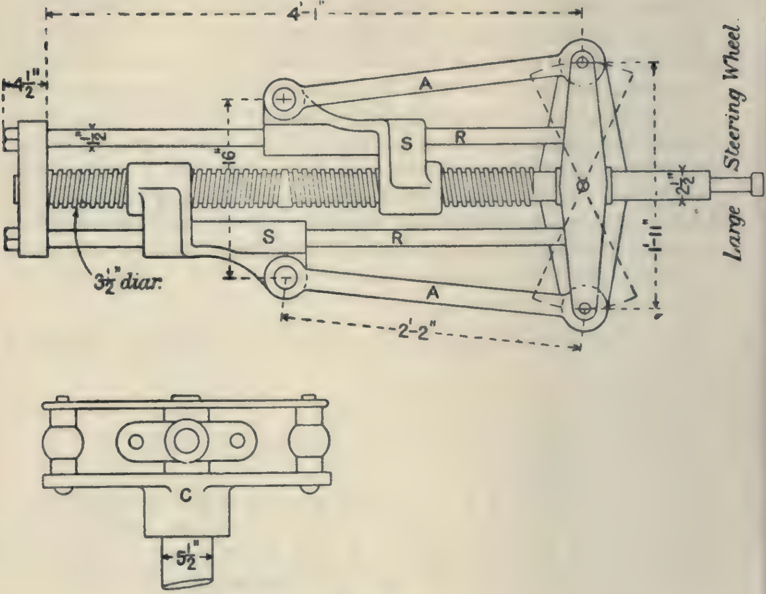


FIG. 164.

Rods A.—Of steel.

Nuts.—Gunmetal or phosphor bronze.

Ques. Describe briefly the steam pumping and drainage arrangements of a ship, detailing where each steam pump draws from and delivers to.

Ans. (**Ordinary Cargo Boat.**)—The main circulating pump works from a crosshead on the main engine, draws water from the sea through the condenser tubes, and discharges overboard. An injection valve is fitted in the engine-room bilge, and connected with the circulating pump, so that if necessary the sea-cock can be closed, and bilge water drawn through the condenser and discharged overboard. A donkey pump worked off separate engine can also be made to do the same work, with separate bilge suctions fitted. Each ballast tank has cast-iron pipe, fitted at the centre with a strum-box on the bottom, to draw water from the compartment; and in the midship tanks there are also winged suction pipes, fitted so that in case of the vessel having a heavy list, and the water lying in the sides, it can be pumped dry. All these pipes lead to one or more valve boxes in the engine room. Limber holes are punched in the floors and in the centre plate, and also drain holes just above the level of the cement, to enable the water to run to the pumps. Air holes are punched at the top of floors and centre plate, to enable the air to pass along to the escape pipes, which are put at the highest end of the compartment. Holes are punched out of the tank knees, and the bilges cemented out, so as to enable the water to run to suctions which are fitted at after end of each hold. The after hold and the engine room generally have a well fitted at the after end, into which the bilge water runs, and is pumped out through suction pipes leading to a valve box in the engine room. The peaks have air-escape pipes fitted in the usual manner. A non-return sea-cock is fitted to flood water-tight compartments when required. The bilge pumps worked from the main engine draw from the valve chests and discharge overboard or on deck for wash-deck service or fire extinguishing. It has also a connection from sea for fire-extinguishing and wash-deck service. A donkey bilge pump with separate bilge suction in engine room is also fitted. A donkey pump for

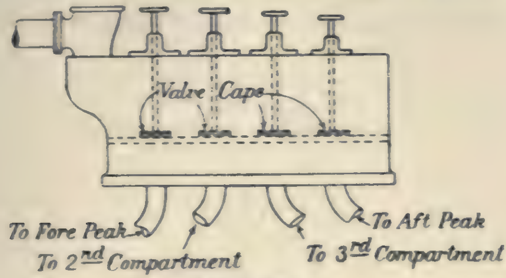


FIG. 165.

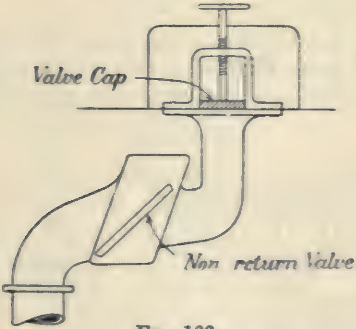


FIG. 166.

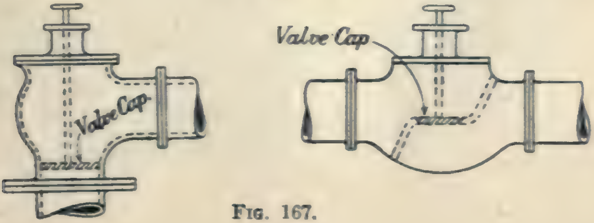


FIG. 167.

feeding the boiler is also fitted with connections from sea, bottom of condenser, and hot well. In a battleship, in the event of the vessel's skin being perforated, a collision mat can be sometimes slipped over the hole, and the circulating pump, which has connection to the ballast valve, can be used to empty the compartment, pass water through condenser, and then discharge overboard by closing the sea valve.

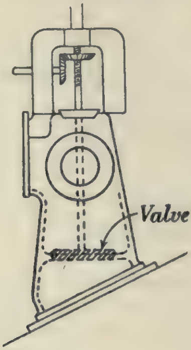


FIG. 168.

Ques. Sketch in detail a large sliding water-tight door, and show how it can be opened and closed from below, as well as from a deck above water. Describe any form of indicator fitted for showing whether the door is open or shut.

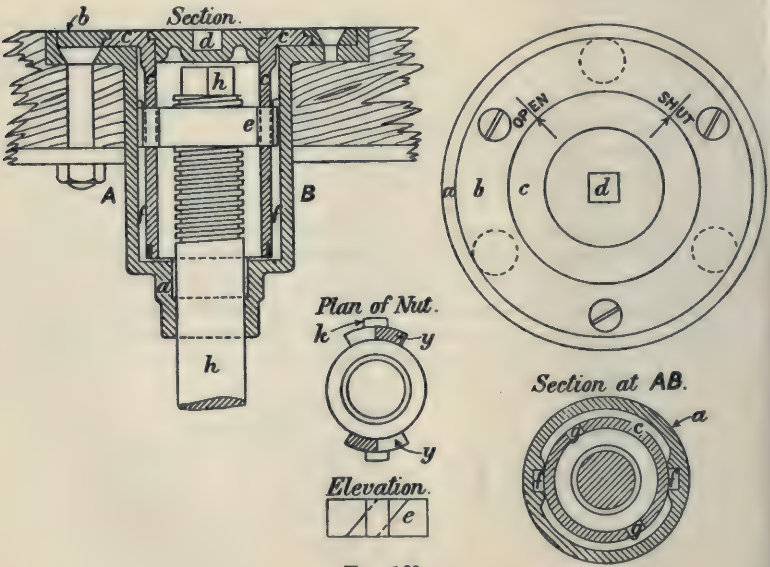


FIG. 169.

Ans. The indicator consists of an outer case, A, fastened in the deck as shown in sketch, with upper surface flush to deck, with a revolving cylinder, C, inside, and is worked as follows: The rod *h* threaded (shown in sketch) is screwed to the door as shown in the sketch of door, and at the top a nut, E, is fitted slackly on the rod, with its outer arms, K, fitting in vertical grooves on the outer case, which will not allow the nut to revolve, but will allow it to slide vertically. Around the cylinder C, which is free to revolve, are two spiral grooves passing about quarter way round the cylinder. When the rod

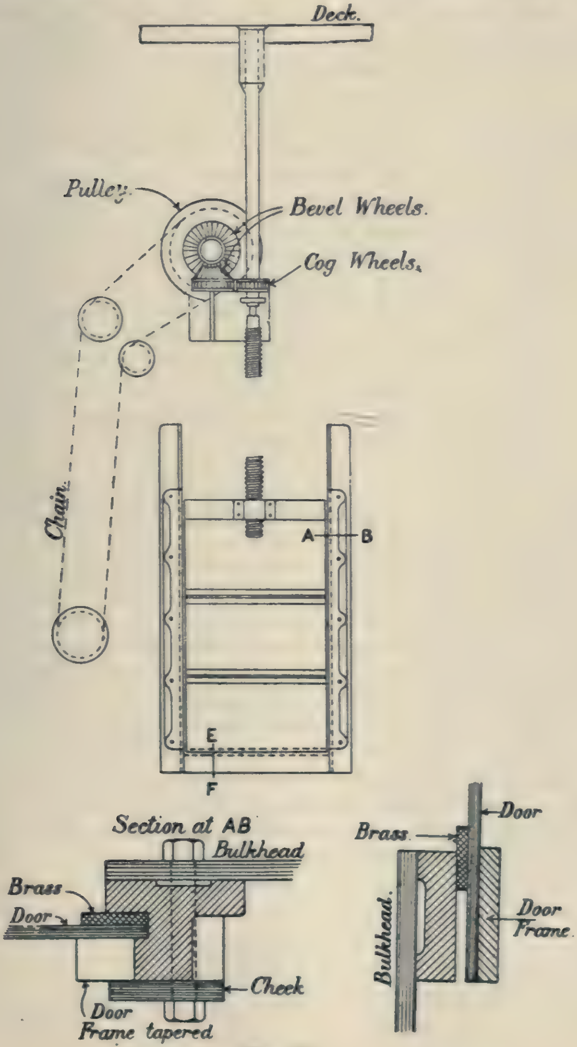


FIG. 170.

is turned, the nut E slides in the grooves F, and the arms Y, working in the spiral grooves, force the cylinder round. A narrow point on the deck plate of the revolving cylinder moves round, and the two marks O and P indicate when the door is open or shut. The revolving cylinder is kept in its place by a holding-down ring *b*.

Ques. Show how you take account of and prepare for going into place a stringer plate for the upper deck.

Ans. First find the position of the stringer plate from the plan, and then go to the ship and make a template, one edge of which is the line of the deck (at side), and the other the stringer edge, as lined off on ship. Transfer the position of the holes in the beams, and if a plate be already on the ship which has to be overlapped on to the one being prepared, then transfer the position of the holes at the overlapped butt on to the template. Now take the template to the stringer plate, and fasten down at the corners by means of clips. Then transfer the position of the holes on the template on to the plate, and also mark off on one edge the positions of the rivet holes to take the gunwale bar, and on the other the holes to take the edge lap of the next strake of deck plating. Mark off at the proper spacing the position of rivet holes at the other end of the plate, to take the overlap butt of the next stringer plate. Mark the correct edges of the plate as it has to be fitted, and then punch and sheer it, taking care to punch from the faying surface in all cases. The plate can now be hoisted into position, and secured by means of nuts and bolts till it is riveted, after being put through the rolls, if necessary, to remove any slight buckling which may be in the plate.

Ques. Describe the shaping and marking off operations on a tee bulb beam before being fitted in its place in the ship.

Ans. First take the beam as it comes into the yard, and nick on it the centre line of ship, and also the extremities as supplied on the beam mould from the loft. Then chalk on the horizontal flange the positions of the deck-plate edges. Mark off and punch between these marks holes spaced seven diameters apart, the holes being reeled; that is, one hole on one side of the flange, and the next on the other. After doing this, bend the beam to the correct camber, as supplied by the beam mould. Welded knees are welded on, and cut to the correct level. Then punch one hole in the corner of each knee, so that it can be bolted to the frame, until the frames and beams have been plumbed and horned, when the remaining holes in the knee can be drilled. The holes to take the rivets through plate edges can be either drilled or beared after the edges have been lined off.

Ques. Sketch on a large scale—

(1) A large through rivet for bottom plating.
(2) A through bolt for securing deck planking.
(3) A bolt for fastening the bottom planking of a sheathed ship.

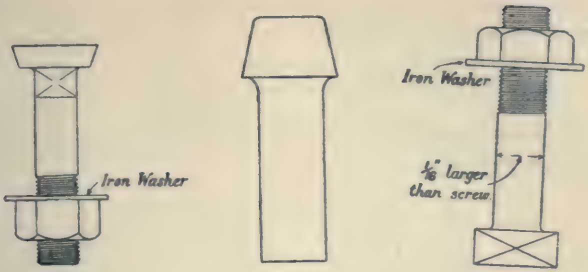


FIG. 171.

Ques. Sketch the different kinds of rivet heads and points, and state where each is used.

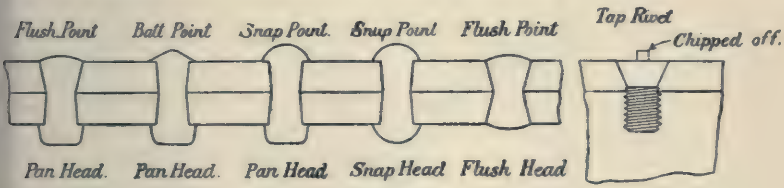


FIG. 172.

Ans. (1) **Pan-head Rivets.**—These rivets are perhaps the most used in shipbuilding, and may have three different kinds of clinch or point.

(*a*) A point called a boiler point, which is hammered to a V-shape, and is used where a rivet will not be readily observed.

(*b*) A point called "snap," which is formed by means of a snap placed over the end of the rivet where it is hot, and hammered into this shape. This is used in bulkheads, casings, etc., to give them a more finished appearance.

(*c*) A point called "full-flush point" is used in decks and shell. It makes good water-tight work.

(2) **Cuphead Rivets.**—This rivet has the same clinches as the panhead.

(*a*) Boiler, snap, and hammered point.

(*b*) Cup, snap, and countersunk.

(3) **Countersunk Rivets.**—This rivet has the same point as the previous ones—hammered or boiler, snap, and countersunk.

This last is used when a flush job is wanted.

(4) **The Hydraulic and Plug-headed Rivets.**—The former is used in transverse framing, and is made by a hydraulic machine. The latter is now almost entirely done away; it was used occasionally in warships. It is sometimes used when a countersunk hole has been finished too large.

There are two separate classes of rivets used—thin-necked and thick-necked rivets. The thick-necked is the most often used, as it is the stronger, and makes a more water-tight job.

NOTE.—Plates are always punched from the faying surface. In places where the thickness of material is too great to allow of rivets being used, the tap rivet is made use of. Examples—

(1) Armour plates.
(2) Connecting a plate to a casting.

Ques. Sketch a cast-steel stern frame for a single-screw steamer, and give particulars of riveting.

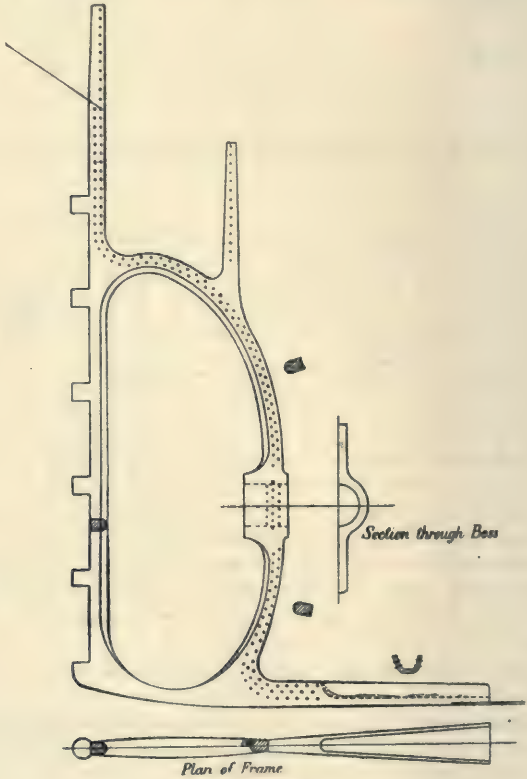


FIG. 173.

Ans. (1) Stern-post cast in one piece.

(2) Rivets spaced five diameters apart.

(3) Tap rivet holes in under side of boss, tapped when plating is in position and secured.

(4) Rivets in boss to be as square to surface as possible.

(5) Row of rivets next aperture to be exact rule spacing for caulking water-tight.

CHAPTER XV.

BOARD OF EDUCATION EXAMINATION PARTICULARS.

USEFUL CONSTANTS.

1 inch = 25·40 millimetres.
1 gallon = 0·1604 cubic foot = 10 lb. of water at 62° F.
1 knot = 6080 feet per hour.
Weight of 1 lb. in London = 445,000 dynes.
One pound avoirdupois = 7000 grains = 453·6 grammes.
1 cubic foot of water weighs 62·3 lb.
1 cubic foot of air at 0° C. and 1 atmosphere weighs 0·0807 lb.
1 cubic foot of hydrogen at 0° C. and 1 atmosphere weighs 0·0055 lb.
1 foot-pound = $1{\cdot}3562 \times 10^7$ ergs.
1 horse-power hour = 33000 × 60 foot-pounds.
1 electrical unit = 1000 watt-hours.
Joule's equivalent to suit Regnault's H is—

774 ft.-lb. = 1 Fahr. unit
1393 ft.-lb. = 1 Cent. „

1 horse-power = 33,000 foot-pounds per minute = 746 watts.
Volts × ampères = watts.
1 atmosphere = 14·7 lbs. per square inch = 2116 lbs. per square foot = 760 mm. of mercury = 10^6 dynes per sq. cm. nearly.
A column of water 2·3 feet high corresponds to a pressure of 1 lb. per square inch.
Absolute temp., $t = \theta°$ C. + 273·7°.
Regnault's H = $606{\cdot}5 + 0{\cdot}305\theta°$ C. = $1082 + 0{\cdot}305\theta°$ F.
$pu^{1{\cdot}0646} = 479$.

$$\log_{10} p = 6{\cdot}1007 - \frac{B}{t} - \frac{C}{t^2},$$

where $\log_{10} B = 3{\cdot}1812$, $\log_{10} C = 5{\cdot}0882$.

p is in pounds per square inch, t is absolute temperature Centigrade.

u is the volume in cubic feet per lb. of steam.

$\pi = 3{\cdot}1416$.

One radian = 57·30 degrees.

To convert common into Napierian logarithms, multiply by 2·3026.

The base of the Napierian logarithms is $e = 2{\cdot}7183$.

The value of g at London = 32·182 feet per sec. per sec.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						4	9	13	17	21	26	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	37
11	0414	0453	0492	0531	0569						4	8	12	15	19	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	19	22	26	30	33
12	0792	0828	0864	0899	0934	0969					3	7	11	14	18	21	25	28	32
							1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	7	10	13	16	20	23	26	30
						1303	1335	1367	1399	1430	3	7	10	12	16	19	22	25	29
14	1461	1492	1523	1553							3	6	9	12	15	18	21	24	28
					1584	1614	1644	1673	1703	1732	3	6	9	12	15	17	20	23	26
15	1761	1790	1818	1847	1875	1903					3	6	9	11	14	17	20	23	26
							1931	1959	1987	2014	3	5	8	11	14	16	19	22	25
16	2041	2068	2095	2122	2148						3	5	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	15	18	21	23
17	2304	2330	2355	2380	2405	2430					3	5	8	10	13	15	18	20	23
							2455	2480	2504	2529	2	5	7	10	12	15	17	19	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	16	19	21
						2672	2695	2718	2742	2765	2	5	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5776	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
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43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
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45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8

LOGARITHMS.

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52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
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55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
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69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

ANTILOGARITHMS.

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·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
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·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

Angle.		Chord.	Sine.	Tangent.	Cotangent.	Cosine.			
Degrees.	Radians.								
0°	0	0	0	0	∞	1	1·414	1·5708	90°
1	·0175	·017	·0175	·0175	57·2900	·9998	1·402	1·5533	89
2	·0349	·035	·0349	·0349	28·6363	·9994	1·389	1·5359	88
3	·0524	·052	·0523	·0524	19·0811	·9986	1·377	1·5184	87
4	·0698	·070	·0698	·0699	14·3007	·9976	1·364	1·5010	86
5	·0873	·087	·0872	·0875	11·4301	·9962	1·351	1·4835	85
6	·1047	·105	·1045	·1051	9·5144	·9945	1·338	1·4661	84
7	·1222	·122	·1219	·1228	8·1443	·9925	1·325	1·4486	83
8	·1396	·140	·1392	·1405	7·1154	·9903	1·312	1·4312	82
9	·1571	·157	·1564	·1584	6·3138	·9877	1·299	1·4137	81
10	·1745	·174	·1736	·1763	5·6713	·9848	1·286	1·3963	80
11	·1920	·192	·1908	·1944	5·1446	·9816	1·272	1·3788	79
12	·2094	·209	·2079	·2126	4·7046	·9781	1·259	1·3614	78
13	·2269	·226	·2250	·2309	4·3315	·9744	1·245	1·3439	77
14	·2443	·244	·2419	·2493	4·0108	·9703	1·231	1·3265	76
15	·2618	·261	·2588	·2679	3·7321	·9659	1·218	1·3090	75
16	·2793	·278	·2756	·2867	3·4874	·9613	1·204	1·2915	74
17	·2967	·296	·2924	·3057	3·2709	·9563	1·190	1·2741	73
18	·3142	·313	·3090	·3249	3·0777	·9511	1·176	1·2566	72
19	·3316	·330	·3256	·3443	2·9042	·9455	1·161	1·2392	71
20	·3491	·347	·3420	·3640	2·7475	·9397	1·147	1·2217	70
21	·3665	·364	·3584	·3839	2·6051	·9336	1·133	1·2043	69
22	·3840	·382	·3746	·4040	2·4751	·9272	1·118	1·1868	68
23	·4014	·399	·3907	·4245	2·3559	·9205	1·104	1·1694	67
24	·4189	·416	·4067	·4452	2·2460	·9135	1·089	1·1519	66
25	·4363	·433	·4226	·4663	2·1445	·9063	1·075	1·1345	65
26	·4538	·450	·4384	·4877	2·0503	·8988	1·060	1·1170	64
27	·4712	·467	·4540	·5095	1·9626	·8910	1·045	1·0996	63
28	·4887	·484	·4695	·5317	1·8807	·8829	1·030	1·0821	62
29	·5061	·501	·4848	·5543	1·8040	·8746	1·015	1·0647	61
30	·5236	·518	·5000	·5774	1·7321	·8660	1·000	1·0472	60
31	·5411	·534	·5150	·6009	1·6643	·8572	·985	1·0297	59
32	·5585	·551	·5299	·6249	1·6003	·8480	·970	1·0123	58
33	·5760	·568	·5446	·6494	1·5399	·8387	·954	·9948	57
34	·5934	·585	·5592	·6745	1·4826	·8290	·939	·9774	56
35	·6109	·601	·5736	·7002	1·4281	·8192	·923	·9599	55
36	·6283	·618	·5878	·7265	1·3764	·8090	·908	·9425	54
37	·6458	·635	·6018	·7536	1·3270	·7986	·892	·9250	53
38	·6632	·651	·6157	·7813	1·2799	·7880	·877	·9076	52
39	·6807	·668	·6293	·8098	1·2349	·7771	·861	·8901	51
40	·6981	·684	·6427	·8391	1·1918	·7660	·845	·8727	50
41	·7156	·700	·6561	·8693	1·1504	·7547	·829	·8552	49
42	·7330	·717	·6691	·9004	1·1106	·7431	·813	·8378	48
43	·7505	·733	·6820	·9325	1·0724	·7314	·797	·8203	47
44	·7679	·749	·6947	·9657	1·0355	·7193	·781	·8029	46
45°	·7854	·765	·7071	1·0000	1·0000	·7071	·765	·7854	45°
			Cosine.	Cotangent.	Tangent.	Sine.	Chord.	Radians.	Degrees.
								Angle.	

NAVAL ARCHITECTURE SYLLABUS.

TABLES will be provided, and candidates will be restricted to the use of these tables, and will not be allowed to bring with them into the examination room any other mathematical or logarithm tables. Slide rules may be used.

Compulsory questions may be set at the examination.

STAGE 1.

I. **Practical Shipbuilding.**—The usual methods of forming, fixing in place, and connecting together the component parts of the structure of a steel or iron ship, including the keel; the framing, both transverse and longitudinal; the stem and stern-post; the bottom or shell plating, inner and outer; and the keelsons, side stringers, beams, pillars, deck stringers and plating, bulkheads, ceilings, and wood decks. The wood and copper sheathing of sheathed ships. The framing, planking, etc., of composite ships. The tools and appliances used in ordinary ship work.

Details of laying building blocks; construction of rudders, bilge keels, water tight and other bulkheads, supports to engines, boilers, and shafting.

The qualities of various materials used in shipbuilding, and the tests to which they are subjected; and the precautions to be observed in working plates and angles, both hot and cold, and the effects of punching and drilling holes.

II. Drawings to a given scale from a simple sketch that will be furnished.

The examination in practical shipbuilding will relate essentially to steel ships; but one or two questions respecting the building of composite ships may be asked.

STAGE 2.

I. **Practical Shipbuilding.**—Description and hand sketches of detail fittings of ships, such as steering gear and principal auxiliary machinery, appliances used in working the ship; anchor and capstan gear; masts and fittings in connection therewith, ventilation and coaling arrangements; pumping and draining.

Precautions necessary to prevent deterioration of hull, while building and while on service.

II. **Laying off.**—Comprising a knowledge of the work carried on in the mould loft for the purpose of fairing up a set of lines, including traces of keelsons, edges of shell plating, tank margins, rib-bands, etc., and transferring the frame and other lines to the scrieve board; obtaining the dimensions for ordering the shell plating, floors, and inner bottom plating; making and marking rib-bands; shearing edges of shell plating on the frames; making templates or skeleton patterns for stem, stern-post, propeller bracket forgings or castings.

III. **Ship Calculations.**—The fundamental conditions to be fulfilled in order that any body may float freely and at rest in still water. Definition of stable equilibrium. Computations of areas of plane curves and of the immersed volume of a ship's hull. The weight of water displaced by a given immersed volume, and its relation to the density of the water. The specific gravities of the principal materials employed in shipbuilding, and calculations of the weight of materials, and of simple parts of a ship's structure.

The use of Simpson's and other rules for finding the position of the centre of gravity of plane areas and for calculating the position of the centre of buoyancy. Graphic or geometrical methods of finding displacement and position of the centre of buoyancy. Definitions of block, prismatic, water-plane, midship area, and other similar coefficients.

IV. **Drawing.**—A more difficult drawing will be given than for Stage 1.

STAGE 3.

I. **Practical Shipbuilding.**—The structural arrangements necessary to resist the longitudinal and transverse stresses to which ships are liable in still water and amongst waves, and the arrangements to resist local stresses. Methods of determining the sizes of structural parts and of detail fittings, making out midship sections to the rules of the principal classification societies; flat and vertical keel, inner bottom, shell, deck, and other plating plans; framing, beam, keelson and stringer plans; details of forging and castings. Making out general and detailed arrangement plans for the various types of ship.

DETERMINATION OF FORM OF INTERSECTIONS OF SURFACES.

II. **Laying off.**—Expanding the plating of longitudinals by the geometric or blocking-up methods; expanding stern plating, rudder trunking, mast plating, obtaining the true shape of a hawse hole in the deck or shell, and similar practical problems. Constructing and fairing the form of a twin screw bossing. Laying off problems peculiar to composite ships.

III. **Ship Calculations.**—Curves of displacement and of tons per inch immersion; definitions of centre of flotation, centre of buoyancy, metacentre, and metacentric height; rules for calculating positions of transverse and longitudinal metacentres; metacentric diagrams, their construction and use.

Displacement sheet and arrangement of calculations made thereon.

Definitions of change of trim; moment to change trim.

Change of trim due to moving weights on board, and that due to the addition or removal of weights.

Inclining experiment to ascertain the position of centre of gravity of a vessel and the precautions taken to ensure accuracy.

Launching arrangements.

Launching diagram and curves in connection therewith.

Calculation of strength of simpler parts of ships' structures, such as tie plates, butt straps, and laps; spacing and strength of iron and steel rivets. Calculation of weights of parts of ships' structures, such as decks and bulkheads.

HONOURS.

No candidate will be credited with a success in Honours who has not obtained a previous success in Stage 3 (or Honours, Part I.).

Proofs of Simpson's and other rules for obtaining areas and moments.

Approximate and detailed calculations relating to the weight and position of centre of gravity of hull.

Coefficients of weight of hull and machinery for various types of ships; also coefficients of position of centre of gravity of the ship.

Calculations for strength of parts of a ship's structure such as decks, side and bottom plating.

Calculation of sheering forces and bending moments acting on a ship floating in still water, and amongst waves; curves of loads, sheering forces, and bending moments, and their relation to one another. Equivalent girder and stress on material.

Statical and dynamical stability; Atwood's and Moseley's formulæ, and methods of calculating stability based thereon. Experimental methods of obtaining stability at any angle. Use of Amsler's integrator for calculating stability. Curves of stability, their construction and uses. Cross curves of stability.

Heeling produced by wind pressure on sails.

The principles of water-tight subdivision of war and merchant ships.

Calculation of alteration of trim and metacentric height due to admission of water into a compartment.

Resistance of ships. Froude's experiments on skin friction; Froude's law of comparison for vessels at corresponding speeds.

Methods of calculating wetted surfaces.

Methods of calculating the horse-power to drive a vessel at a given speed.

Definitions of slip and pitch of propeller, effective horse-power, propulsive coefficient, and Admiralty constant, and values of the two last in typical cases.

Speed of ships on trial, methods adopted and precautions necessary to obtain accurate speed data. Progressive trials.

Calculations relating to steering of ships. Methods of determining the size of rudder heads and the stresses on rudders, balanced and unbalanced.

Fixing the dimensions of ships to fulfil given simple conditions such as speed and weight carrying; methods of making sheer draughts.

Those candidates who answer the questions in the written paper in a sufficiently satisfactory way will be required to undergo a practical examination at South Kensington or some other centre. This examination will be held on consecutive days. The time allowed for work on each day will be seven hours—three hours in the morning and four hours in the afternoon.

Candidates' practical knowledge as Naval Architects will be tested by giving them practical work of the following character:—

(1) Making a set of lines to given dimensions and displacement.

(2) Making outline plans showing the general arrangement of a vessel of one of several specified types.

(3) Preparing structural midship sections or other structural sections or plans from the sheer drawing and specified scantlings.

Candidates must themselves provide all drawing instruments, moulds, battens, straight-edges, squares, etc., and all other necessaries, except drawing-boards, drawing paper, batten weights, and drawing battens and straight edges over two feet in length, which will be furnished by the Board of Education.

Neatness and accuracy in drawing will be insisted on.

No candidate will be classed in Honours who is not successful in the practical examination.

BOARD OF EDUCATION, SOUTH KENSINGTON, LONDON, 1904.

SUBJECT IV. NAVAL ARCHITECTURE.

STAGE 1.

GENERAL INSTRUCTIONS.

If the regulations are not attended to, your paper will be cancelled.

Immediately before the Examination commences, the following

REGULATIONS ARE TO BE READ TO THE CANDIDATES.

Before commencing your work, you are required to fill up the numbered slip which is attached to the blank examination paper.

You may not have with you any books, notes, or paper other than that supplied to you for use at this examination.

You are not allowed to write, draw, or calculate on your paper of questions.

You must not, under any circumstances whatever, speak to or communicate with another candidate. Those superintending the examination are not at liberty to give any explanation bearing upon the paper.

You must remain seated until your papers have been collected and then quietly leave the examination room. No candidate will be allowed to leave before the expiration of one hour from the commencement of the examination, and none can be readmitted after having once left the room.

All papers, not previously given up, will be collected at 10 o'clock.

If any of you break any of these regulations, or use any unfair means, you will be expelled, and your paper cancelled.

Before commencing your work, you must carefully read the following instructions:—

You are permitted to answer only *eight* questions.

You must attempt No 11. Two of the remaining questions should be selected from the Calculations; and the rest from the Practical Shipbuilding section.

Put the number of the question before your answer.

You are to confine your answers *strictly* to the questions proposed.

The value attached to each question is shown in brackets after the question. A full and correct answer to an easy question will in all cases secure a larger number of marks than an incomplete or inexact answer to a more difficult one.

The Examination in this subject lasts for four hours.

PRACTICAL SHIPBUILDING.

In questions 1 to 9 inclusive, your answers may be given in reference to any type of ship. The type selected should be named in each question.

1. Make a sketch so as to show clearly the connections in a double-bottomed ship of the margin plate to the floor plate and wing bracket. Give scantlings. (10)

2. State the order of fitting and riveting the different parts that form the structure of the double bottom. (10)

3. Show by a sketch how a stanchion supporting a shade or boat deck may be connected to the bulwark plating. Give approximate scantlings. (10)

4. Show how a teak hand-rail is fitted and connected to a line of rail stanchions. (10)

5. Sketch a beam knee or a beam bracket and its connections to the beam and frame. Give scantlings and show the rivet connections. (10)

6. Make a rough sketch showing in plan how deck-tie plates are usually fitted. (10)

7. Sketch an arrangement for stepping a mast on a bulkhead or on a deck. (10)

8. How are the mainstays connected to the mast? Illustrate by a sketch. (10)

9. State the order of doing the work in laying a wood deck. How are the butts of the planks arranged? (10)

10. Make a sketch of one of the following:—
- (*a*) Mushroom ventilator.
- (*b*) Fairlead.
- (*c*) Portable pillar. (10)

DRAWING.

11. Enlarge sketch No. 11 on diagram K to a scale twice the size upon which it is drawn. (20)

CALCULATIONS.

12. State clearly the conditions that govern the stability of a body floating freely at rest in still water. What is the effect of moving a weight through a distance fore-and-aft on board a ship? Explain how a vessel may have a transverse inclination at the end of a voyage. (10)

13. A rectangular vessel of uniform section 20′ 0″ × 10′ 0″ × 4′ 0″ floats at a uniform draught in salt water; the vessel itself weighs three tons, and it is partly filled with seven tons of salt water. Find the draught.

If the volume that is now filled with salt water were filled with fresh water, what would be the change in draught? (15)

14. The area of the whole water-plane of a ship floating in the upright position is equal to 488 square feet; the sections are equally spaced, and the half-ordinates of the sections at the water-plane are as follows:—0·2, 4·0, 5·0, 5·4, 5·0, 3·8, 0·2 feet. Find the length of the water-plane. (15)

15. A teak rail is 8″ broad × 3″ thick. It is rounded off in a semicircle at each side: find the weight of a length of 120′ 0″. Find also the weight of yellow pine deck $1\frac{3}{4}$″ thick that covers an area of 360 square feet. (10)

16. Find the weight per foot of length of a steel tee bar 5″ × 6″ × $\frac{1}{2}$″, and of a steel angle bar 3″ × $2\frac{1}{2}$″ × $\frac{1}{4}$″. Find also the thickness of steel plate if the weight per square foot of area is 460 lbs., 22 lbs., 5 lbs., respectively.

What is the weight per cubic foot of copper and of brass? (10)

SUBJECT IV. NAVAL ARCHITECTURE.

STAGE 2, STAGE 3, AND HONOURS.

GENERAL INSTRUCTIONS.

If the regulations are not attended to, your paper will be cancelled.

Immediately before the Examination commences, the following

REGULATIONS ARE TO BE READ TO THE CANDIDATES.

Before commencing your work, you are required to fill up the numbered slip which is attached to the blank examination paper.

You may not have with you any books, notes, or paper other than that supplied to you for use at this examination.

You are not allowed to write, draw, or calculate on your paper of questions.

You must not, under any circumstances whatever, speak to or communicate with another candidate. Those superintending the examination are not at liberty to give any explanation bearing upon the paper.

You must remain seated until your papers have been collected, and then quietly leave the examination room. No candidate will be allowed to leave before the expiration of one hour from the commencement of the examination, and none can be readmitted after having once left the room.

All papers, not previously given up, will be collected at 10 o'clock.

If any of you break any of these regulations, or use any unfair means, you will be expelled, and your paper cancelled.

Ins [illegible]

Before commencing your work, you must carefully read the following instructions:—

You may take Stage 2, or Stage 3, or, if eligible, Honours, but you must confine yourself to one of them.

Put the number of the question before your answer.

You are to confine your answers *strictly* to the questions proposed.

The value attached to each question is shown in brackets after the question. A full and correct answer to an easy question will in all cases secure a larger number of marks than an incomplete or inexact answer to a more difficult one.

The Examination in this subject lasts for four hours.

STAGE 2.

INSTRUCTIONS.

Read the General Instructions above.

You are permitted to answer only *eight* questions.

You must attempt Nos. 32 and 33. The remaining questions may be selected from any part of the paper in this stage, provided that one or more be taken from each section, viz. Practical Shipbuilding, Laying Off, and Calculations.

PRACTICAL SHIPBUILDING.

21. In what part of a ship and under what conditions does wood most contribute to the longitudinal strength of a vessel? What stresses are liable to come upon the structure of a ship in a seaway? What effect has the distribution of the heavy weights in a ship on those stresses? (20)

22. Make a sketch showing a section and scantlings of a fender or "rubbing piece" for protecting a ship's side. (20)

23. A plate is intended to be fitted under the counter of a vessel where there is a great variation in form of cross-section, and also in the fore-and-aft curvature; describe the whole of the operations in connection with the plate from the time it enters the yard until it is finally riveted in place. (20)

24. Give a sketch and scantlings with disposition of rivets of a butt joint of shell plates with a single butt strap. (20)

25. How is a building berth prepared before the keel is laid? Describe in detail how the keel blocks are laid. (20)

26. Make a sketch, giving scantlings, of a suitable arrangement of boiler seating for a cylindrical or for a water-tube boiler. (25)

27. Describe the tests to which rivets are usually submitted. (20)

28. Compare the qualities of mild and of high tensile steel. In what part of the structure of a ship would it be of advantage to have high tensile steel, and for what reason? (20)

LAYING OFF.

29. For what parts of the structure is it usually necessary to make moulds? Describe, with the aid of sketches, how to make a complete working mould for a stem. (20)

30. When the lines of a ship have been faired in the loft, how are the finished offsets usually lifted and tabulated? (20)

31. How are the bevels of the beam knees or beam brackets obtained, and in what form is this information sent out from the loft? Describe how to draw on the scrieve board the lines for a hold stringer. (20)

DRAWING.

32. What does sketch No. 32 on Diagram L represent? Enlarge it to twice the scale upon which it is drawn. (35)

CALCULATIONS.

33. State Simpson's first and second rules.

Find the area and longitudinal position of the C.G. of the water-plane whose half-ordinates are: 0·1, 3·1, 4·0, 3·0, 0·2 feet respectively. Interval = 6 feet. (25)

34. Construct a curve of displacement for a cylindrical vessel, length = 100 feet, diameter = 10 feet; floating with its axis horizontal, and in the plane of flotation. (25)

35. Define "metacentric height." Show how to obtain from the displacement curve a curve giving the heights of the centre of buoyancy in terms of draught. (25)

36. Calculate the weight of a beam, frame and reverse frame, floor plate, etc., for a ship with ordinary floors. Assume dimensions of beam and girth. Assume the floor plate to be triangular. Make the scantlings suitable for the dimensions of the vessel that you choose. (25)

STAGE 3.

INSTRUCTIONS.

Read the General Instructions with Stage 2.

You are permitted to answer only *eight* questions. You must attempt No. 51, and one other question at least should be selected from the Calculations.

PRACTICAL SHIPBUILDING.

41. Sketch a stern-post suitable for a balanced rudder. Give scantlings. (35)

42. Make sections showing the chief differences in the structure of (1) an ordinary three-deck steamer, (2) a turret steamer of about the same depth as (1). Scantlings need not be given. (35)

43. Sketch a plan of part of the inner bottom or tank top of a double-bottomed steamer. Show the connections to the framing and to the longitudinal and transverse bulkheads. (35)

44. Describe, with the aid of sketches, the most suitable arrangement of sheds and machines for working ship plates and angles, having regard chiefly to the economy of transporting the material from one machine to another. (35)

45. Make a sketch of a small portable hydraulic riveter. (30)

46. What methods are employed to preserve the ironwork inside a feed-water or fresh-water tank? (30)

47. Make a sketch showing how the heels of derricks are supported at the mast. Give scantlings. (35)

48. Describe fully by sketches a system of ventilating the hold compartments of a vessel. What system of ventilation would be necessary if the gases liable to collect in the hold were heavier than air? (35)

49. Sketch an anchor crane and its fittings. Give scantlings. (35)

50. Make a sketch showing the method of *stowing* an accommodation ladder. (35)

CALCULATIONS.

51. What do you understand the *displacement* of a ship to be? Find the displacement up to the 6′ 0″ W.L. of the form

defined by the following half-ordinates of sections; the common interval is 30′ 0″:—

No. of section.	Keel.	1′ W.L.	2′ W.L.	4′ W.L.	6′ W.L.
1	0	0	0	0	0
1½	0	5·8	8·2	11·4	14·0
2	0	7·4	10·2	14·6	18·0
3	0	8·2	11·6	16·4	20·0
4	0	6·6	9·2	13·0	16·0
4½	0	4·8	7·0	9·8	12·0
5	0	0	0	0	0

Construct the curve of tons per inch. (45)

52. Describe the inclining experiments. Enumerate the precautions that should be taken. How would you take account of weights to "go in" and weights to "come out" in order to find the vertical position of the C.G. for a certain condition of vessel, say the "light condition"? (40)

53. A total change of trim of 6″ shifts a vessel's C.G. forward through a horizontal distance of 15″. What is the longitudinal metacentric height? Length of water-plane = 200 ft.; displacement = 612 tons. If this change of trim of 6″ takes effect by altering the draft 3½″ forward and 2½″ aft, find the position of the C.G. of the water-plane. (35)

54. Having been given a displacement table, describe how to find the position longitudinally and vertically of the centre of buoyancy corresponding to any of the water-planes. What is the relation between the locus of the C.B. thus found and the curve giving the locus of the C.G.'s of the corresponding water-planes? (40)

55. Describe the method of determining by calculation of the ultimate strength, the most suitable disposition of rivets in—

(1) A lap butt.
(2) A flush butt with double straps.

The plate to be assumed 60″ wide and ½″ thick.

Why is it found necessary generally to put in more rivets than the above method of calculation indicates? (35)

56. Make a sketch of the structural midship section of a steam vessel with one or two decks, giving scantlings, and calculate the weight per frame space of the framing and plating. (35)

HONOURS.

INSTRUCTIONS.

Read the General Instructions with Stage 2 paper.

You are not permitted to answer more than *eight* questions.

NOTE.—*No Candidate will be credited with a success in this Examination who has not obtained a success in an examination corresponding to Stage* 3 *of the same subject* (i.e. *in Honours, or Honours, Part I., under previous regulations*).

61. State the principle by which areas can be found by using any of Tchebyscheff's Rules. Draw up a convenient form of table by which the displacement of a ship may be calculated, applying any of Tchebyscheff's Rules to integrate vertically or longitudinally. (40)

62. Define "transverse metacentre." The body plan half-sections of a vessel are squares. The vessel floats with sides upright, and the centres of all the sections lie in the plane of flotation. The lengths of the sides of the sections including the end ordinates are as follows: 2, 3·5, 5, 6, 6, 5, 3 feet, and the interval between each section is 15′ 0″. Calculate the transverse B.M. (45)

63. A rectangular barge 80′ 0″ × 15′ 0″ × 8′ 0″ is loaded with 100 tons of cargo, the C.G. of which is slightly to the starboard side, thus causing the barge to have a list. A weight of 2 tons is moved from the centre of the deck through a transverse distance of 6 feet, and then the barge floats level. Taking the weight of barge to be 50 tons, and the height of the C.G. of barge and cargo to be 2′ 0″ from the bottom of the barge, find the original list. (50)

64. Describe how a metacentric diagram is constructed. Give sketches showing the difference in the nature of the metacentric diagrams of:—

(1) Full cargo vessel.
(2) Very fine passenger vessel.
(3) Sailing yacht.
(4) Torpedo boat destroyer. (50)

65. In an empty rectangular vessel 100′ 0″ × 20′ 0″ × 10′ 0″ floating at 5′ 0″ draft, suppose a compartment 10′ 0″ long with its centre at 20′ 0″ from the stem to be flooded, what change of

draft forward and aft will take place? Explain how you could by similar calculations find the percentages of length which could be flooded at different points of the length so that the stem would be just awash. (55)

66. Sketch typical statical stability curves for the following types of vessels :—

(1) Large fine Atlantic liner.
(2) Full cargo steamer.
(3) Sailing ship.

What metacentric height would you associate with each of these types? Show also by sketches the effect on the curve of statical stability due to (1) increasing freeboard, (2) increasing breadth. (55)

67. Obtain an expression for the value of G.Z. in terms of the volumes v_1 and v_2 of the wedges of submersion and emersion, and other necessary terms. (40)

68. Describe how to obtain the locus of the centre of buoyancy for constant displacement and varying angle of heel. How could this curve be obtained from the curve of G.Z.'s if B.G. in the upright condition is known? (45)

69. State the relations between the curves of loads, sheering force, and bending moment. Given the weight curve and the lines of the ship, describe how you would proceed to find the maximum bending moment for the ship on the crest of a given wave. (50)

70. What ratios are used to express the intensity of a bending moment on a ship? Give values of these for typical ships. (40)

71. Describe how progressive speed trials are conducted. Enumerate the precautions that have to be taken. What observations are made in order to obtain an accurate speed curve? Give a method of finding the dead-load friction of the engines from the data of the trial. (50)

72. Describe Froude's experiment on surface friction. Deduce a formula, giving the horse-power required to overcome the frictional resistance of a vessel moving at any given speed. (45)

73. State Froude's law of comparison, and explain how it is applied to determine the resistance of a ship from that of an experimental model.

The wave-making resistance of a 12′ 0″ model is 1·65 lb. at a speed of 500 feet per minute. Find the horse-power to overcome the wave-making resistance of a 300′ 0″ ship of similar form and moving at a corresponding speed. (45)

74. Define surface of buoyancy and surface of flotation. Prove that a surface of buoyancy can have no re-entering parts. Prove that the tangent plane to the surface of buoyancy is parallel to the corresponding plane of flotation. (40)

75. What are the causes that produce uneasy rolling at sea? What methods have been used to minimise rolling at sea? (40)

76. Describe any method or instrument for observing at sea the angle to which a vessel rolls. State approximately the period of rolling of (1) a large battleship, (2) a stiff Channel steamer. (40)

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THE END.

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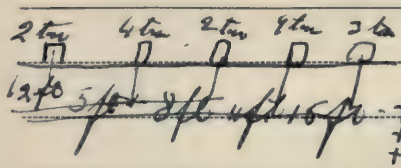
NOTES.	Reference.



sum of moments = 2 t × 2 ft = 4 ft tn
+ 4 × 5 = 26
+ 2 × 6 = 12 ″
+ 4 × 11 = 49 ″
+ 3 × 15 = 45 ″
Total wt 20 180 ″

The above used for C. of buoyancy. and centre of Gravity

Obtain proof of Simpson 1st 2nd 3rd rule.
Checking rule [illegible]

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